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Pomacea Canaliculata in Tram Chim National Park: An Examination of the Golden Apple Snail within Local Vegetation Populations

Justin Loiseau
SIT Study Abroad

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Justin Loiseau
Advisor: Nguyen Huu Thien, PhD
World Learning, SIT Study Abroad: Vietnam Mekong Delta
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Date: 15 May 2009

Abstract

The golden apple snail (*Pomacea canaliculata*) is an invasive species that was first introduced into Southeast Asia in the 1980's. Nearly three decades later, *Pomacea canaliculata* has become a widespread pest that threatens several key crops of the region, including Vietnam's expansive rice fields.

Although the economic implications of the spread of *Pomacea canaliculata* throughout Vietnam are disastrous, the environmental implications are also quite shocking. In Tram Chim National Park, the golden apple snail has shown its ability to survive and thrive off of local grasses and wild rice.

To better understand the threat level of *Pomacea canaliculata* to Tram Chim National Park, this experiment is designed to examine the effect that the golden apple snail has on five common vegetation types. This project will also serve as a way to further establish which vegetation habitats *Pomacea canaliculata* is able to survive and reproduce within.

The questions initially posed during this experiment remain largely unanswered, due to an unfortunate series of events involving grazing water buffalo and village thieves. However, the project provides solid empirical evidence on *Pomacea canaliculata*'s reproductive habits within each vegetation area and the golden apple snail's ability to change the chemical balance of its surrounding environment. This final report also includes an intensive analysis and recommendations section for any future replication.

Acknowledgements

The ability for an undergraduate student untrained in field work to carry out a research project in a foreign country is daunting, to say the least. It was only through the careful preparation, guidance, and constant mentoring of several key people that allowed this project to be seen through to fruition.

First and foremost, it's important to thank Dr. Nguyen Huu Thien for his unwavering help. Dr. Thien's willingness to provide his time and his resources to this project went far beyond my greatest hopes. More than anything else, Dr. Thien helped this project by believing in its ability to provide concrete data to Tram Chim National Park. He understood the limitations of the project and was constantly searching for ways to realistically approach solutions to some of the very complicated questions concerning *Pomacea canaliculata* and Tram Chim National Park. His generosity and his wisdom provided the base on which this entire project stands.

Just as Dr. Thien provided the foundation for this research project, the staff of Tram Chim National Park were the people who helped create the structure. Both figuratively and literally, this project was built with the experience and oversight of the Tram Chim National Park research employees. Mr. Ngûyen Hoàng Minh Hải, the man behind the curtains, is to be thanked for his oversight of the project. His guidance on a day-to-day basis allowed the project to move forward in ways that were both unimaginable at the start and necessary by the end. Mr. Hai was always available to answer an obvious question or suggest an alternative way of thinking. His help and the help of the rest of the staff allowed the project to move from theory to action with as few difficulties as possible.

Finally, it is important to thank SIT Academic Director Dr. Andrew Wyatt, SIT Program Assistant Kieu Thuy Tien and the SIT: Vietnam Mekong Delta program itself. The theories of SIT are both incredible and incredibly challenging. It is only with the most enthusiastic of representatives that a program such as the one SIT aspires to be can truly become meaningful. Dr. Wyatt's help in identifying possible projects and providing the means through which possible projects could work was immense. With Dr. Wyatt's help, Tram Chim National Park became an open door through which anyone, even an unskilled aspiring research scientist, could easily walk through.

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1. INTRODUCTION

Studying *Pomacea canaliculata* within Tram Chim National Park presented many questions to be answered. The main question, however, wasn't *what* to study, but *how* to study it. Although *Pomacea canaliculata* has existed within Asia as an invasive species since the 1980's, nearly all the research done on *Pomacea canaliculata* has been irrelevant to the answers that Tram Chim National Park hopes and needs to find (Thien, 2009). Questions that go beyond financial impact assessments and focus on long-term damage to overall ecosystems are the types of questions that this project hopes to delve into. To better understand the underlying problems of *Pomacea canaliculata* in Tram Chim National Park and Southeast Asia, it's first important to understand its historical presence in the area.

The golden apple snail, *Pomacea canaliculata*, is a native species to South America, where it exists as a contributing member to the local ecosystem. Its resilient nature and efficient reproduction rate allows *Pomacea canaliculata* to survive in areas where many other snail species cannot. Whereas in countries such as Brazil and Peru, *Pomacea canaliculata* is seen as a necessary and vital part of local ecosystems, the same cannot be said for its presence within Southeast Asia (Ghesquiere, 2001).

Since its introduction into Asia in the early 1980's, *Pomacea canaliculata* has wreaked havoc on the economy and biodiversity of Vietnam. *Pomacea canaliculata* was originally brought to Southeast Asia by Taiwanese investors who hoped to use *P. canaliculata* for financial gain. The snail was seen as the answer to many farmers' searches for a cheaper way to feed their fish, poultry, and livestock. If crushed, *Pomacea canaliculata* could serve as a sustainable, organic, and nutrient-rich source of sustenance. The Taiwanese also hoped to introduce the snail as a new food for humans. With 81 calories in a 100 gram serving of *P. canaliculata*, it was thought that the snail would become a welcome addition to any meal. In practice, the golden apple snail was rejected by Southeast Asia as a delicacy, or even a basic food source (Ghesquiere, 2001). The plan to incorporate the snail into Southeast Asia went horribly wrong when, in the mid-1980's the controlled production of *P. canaliculata* became uncontrollable.

Originally limited to two small-scale farms as a joint-venture between Taiwanese and Vietnamese companies, *P. canaliculata* soon spread to nearby ponds and farms, where it was first recognized as a dangerous pest. In 1992, the Vietnamese government made snail farming illegal and introduced several costly control and awareness programs. What may have been a pest to thousands became a pest to millions when, in 1996, seasonal flooding opened the door for the invasion of *P. canaliculata* into the Mekong River (Matthews, 2004).

Over the next decade, the golden apple snail has continued to manipulate the economy and natural environment of Vietnam. There have been and will continue to be movements to eradicate this invasive species, but nothing yet has proven effective enough to reduce *P. canaliculata*'s spread across the Mekong Delta and beyond (Cowie, 2005).

The main threats from *P. canaliculata* can be divided into two categories: economic and environmental. Rice is Vietnam's main export, providing income for nearly 80% of all Vietnamese (CIA Factbook, 2009). The golden apple snail's preferred food is, incidentally, rice. An entire farm can be destroyed in a matter of days, depending on the age of the rice and the density of *P. canaliculata* in the area (Cowie, 2005). For those farmers who are able to control the spread on their farms, the costs in terms of time lost or molluscicides can make a heavy cut into profits. Environmentally, efforts to control *P. canaliculata* have also taken a toll on local ecosystems. Since *P. canaliculata* only lay eggs above water, some farmers will build dikes and flood large areas of land in order to kill these snails. The above-mentioned use of molluscicides can also affect natural species in the area, indirectly killing contributing members of a local ecosystem (Thien, 2009).

Although *P. canaliculata* is most often referred to as a pest to rice farms, this snail has also had devastating effects on natural grasslands in Southeast Asia (Thien, 2009). Tram Chim National Park is one of Vietnam's few protected wetlands. Tram Chim originally gained fame (or infamy) during the Vietnam War, when its dense flooded forests were used as a headquarters for Vietcong soldiers. In an effort to penetrate the area and effectively use napalm, the U.S. Army Corps of Engineers built dikes around Tram Chim (and the entire 700,000 hectare Plain of Reeds) and drained the area. The effect on the Plain of Reeds was enormous, but the natural fertility of the soil soon allowed the area to return to plush grassland after the Vietnam War. Between 1985 and 1998, the area slowly evolved from a commercial fishery and forest plantation to its current status as a national park. The park is most well-known for its status as one of the most important remaining habitats in Vietnam where the endangered Eastern Sarus Crane makes a migratory stop (Thien, 2009).

Current threats to the park are as varied as they are plentiful. From the invasion of species such as *Pomacea canaliculata* or *Mimosa Pigra* to media and policy pressure to control natural burns of forested areas, the staff at Tram Chim National Park face challenges from all angles. The wild grass *Eleocharis dulcis* and wild rice *Oryza rufipogon* make up much of the feeding habitat for the sarus crane, but have come under attack from *Pomacea canaliculata* in the past decade. The existence of these grasslands is vital to both the survival of the sarus crane and Tram Chim National Park. Over 3000 tourists visited last year and the sarus crane is inarguably the park's main attraction (Thien, 2009).

Last semester, SIT student Ann Huston attempted to examine the impact of *Pomacea canaliculata* in various parts of the park. Unfortunately, flawed methodology did not allow her to make any conclusive remarks. She did, however, perform a critique of her experiment and left valuable information that has now been used to create a new experiment within the park (Huston, 2008). Most publications concerning *Pomacea canaliculata* contain more information on the control of the snail than on the specifics of its destructiveness. This may serve as a tool for the park in the future, but it doesn't allow them to rate their need to focus eradication efforts on the *Pomacea canaliculata* versus other threats to Tram Chim National Park.

Much of the data on these snails also stems from its economic threat to rice fields. The Philippines Rice Institute is considered by many to be the expert on *Pomacea canaliculata*, but nearly all its information stems from the desire to eradicate *Pomacea canaliculata* from intensive rice fields using the most financially advantageous (but not environmentally friendly) methods possible (PhilRice, 2009).

Tram Chim National Park needs area-specific data concerning *Pomacea canaliculata*'s effect on wild grasses and rice that exist within the park. This data will not only allow the park to create control and prevention plans, but will also allow them to receive government funding to carry out these plans (Thien, 2009). By combining general knowledge with area-specific field-based experiments, the staff of Tram Chim National Park will be able to better understand the threat level of *Pomacea canaliculata* to the natural ecosystem. With this higher level of comprehension, they will be able to make informed decisions on how much effort should be focused on *Pomacea canaliculata* versus other invasive species, government regulations, or social issues.

2. METHODOLOGY

Since the main issue concerning *Pomacea canaliculata* and Tram Chim National Park is the lack of overlapping empirical data, it was decided that the most effective and efficient way of gathering data would be to create a field-based experiment. With the help of Dr. Ngyuyen Huu Thien, five plant species were identified as being the most important plants to examine within Tram Chim National Park. *Eleocharis atropurpurea, Eleocharis dulcis*, *Panicum repens*, *Oryza rufipogon*, and *Melaleuca cajuputi* are all local plants within the park that contribute to its historic diversity and natural ecosystem.

The original study questions that formed the basis for this experiment methodology are as follows:

- What is the effect of different densities of *Pomacea canaliculata* on the health of *Eleocharis atropurpurea, Eleocharis dulcis*, *Panicum repens*, *Oryza rufipogon*, and *Melaleuca cajuputi* within Tram Chim National Park?
- What is the effect of different densities of *Pomacea canaliculata* on the surrounding water environment?

- At what densities of *Pomacea canaliculata* does the effect on natural vegetations become observable and quantifiable?

The design of the experiment is simple. Different quantities of *Pomacea canaliculata* will be cordoned off into 2 meter by 2 meter mesh cages within areas of different vegetation. The main flaw of the previous SIT student Ann Huston came from her cage design and the ability for the snails to escape. Therefore, several changes have been made to the design of the cage. Firstly, the cage will be covered on all sides, including the top. In order to keep the experiment as similar to the natural habitat as possible, poles holding up the mesh sides will be placed on the outside of the mesh. In this way, *Pomacea canaliculata* will not be able to lay their eggs on the poles, a common occurrence in the previous experiment. The mesh will also be pushed deep within the mud, as *Pomacea canaliculata* have the ability to burrow up to 15 cm below ground level (Ghesquiere, 2001). With four cages at each location and five separate locations, there will be twenty cages total.

The only manipulation of the natural environment will be the addition of *Pomacea canaliculata* to the area. In each of the five experiment areas, four cage areas will be set up. It is absolutely imperative that the plant vegetation within each cage area consist entirely of the plant species to be studied. The water depth should also be approximately 15 centimeters deep in order to create a livable environment for *Pomacea canaliculata*. Three of the snail cages will be surrounded by netting on all sides. These cages will hold 8, 16, and 24 snails. The final cage will be marked with poles and serves as the control for that plant species. No snails will be added to this area and the area will be manipulated in no way. Each snail will be marked with a waterproof marking to make identification simple.

During the initial installation of snails into their cages, the total weight of all snails within each cage will be weighed. On the 14^{th} day of the experiment, the snails will be recollected and reweighed. For the duration of the 14 day experiment, each cage will be examined every two days. As much as possible, data should be taken from each cage at the same time of day to reduce variability. Each cage will be examined for *Pomacea canaliculata* egg clusters. Their location and quantity will be recorded for each data collection period.

The vegetation data is arguably the most important aspect of this experiment, although it is also the most difficult to quantify. Initially, a stem count will be made to determine the quantity of plants within each cage. At each data collection period, an additional stem count will be made and any plant destruction will be noted. This will be most evident in broken stems and discoloration.

General data will also be recorded at each cage. This data might serve as an indicator for how certain densities of *Pomacea canaliculata* directly affect the environment of Tram Chim National Park, thus indirectly affecting the local plant species of the park. This data will include temperature, water pH, dissolved oxygen percentage, electric conductivity, nitrate concentration, phosphate concentration, iron concentration, and water depth. Any other observations will be recorded in the work journal as needed.

At the conclusion of the 14 day experiment, all cages will be dismantled and the snails in each cage will be weighed. *Pomacea canaliculata* and their egg clusters within the cages will be destroyed.

Data to be gathered at each cage location:

- Plant species
- Number of snails
- Day 0 initial snail weight (grams)
- Day 14 final snail weight (grams)
- Time of data collection
- pH
- Temperature (°C)
- Electric conductivity (µS/cm)
- Dissolved oxygen (%)
- Water depth (cm)
- NO_3^- (ppm)
- PO_4^{3-} (ppm)
- Fe^+ (ppm)
- Egg cluster count (quantity)
- Egg cluster location (net, plant, water)

Equipment used:

- work journal
- writing utensil
- 15 8 meter long x 3.75 meter high connected pieces of fish net
- 80 1 meter tall eucalyptus poles
- 100 meters of cord
- Electronic pH reader
- Electronic dissolved oxygen reader
- Electronic thermometer
- Electronic electric conductivity meter
- Tape measure
- Hanna Instrument Ion Specific Meters
    - NO_3^-
    - PO_4^{3-}
    - Fe^+
- Computer
- Microsoft Office (Word, Excel, Powerpoint)
- Internet access

3. RESULTS

3.1 Difficulties and Limitations

"In field work, always expect the unexpected." – Dr. Andrew Wyatt

As the above quotation suggests, there are sometimes unknown or uncontrollable variables that force their ways into one's attempts to carry out a controlled field experiment. Therefore, it is important to understand the limitations of this experiment before presenting its results. It is only by fully understanding the difficulties that this experiment encountered that one can begin to evaluate the following results.

3.1.1 Cage Design

First and foremost, it is necessary to acknowledge that the cage design for the *Pomacea canaliculata* was, once again, flawed. In the proposed methodology, it was decided that supporting poles for the cages would be placed outside of each cage area. Upon arrival at the proposed cage sites, Mr. Hai advised against this construction idea, so as to have a more sturdy structure on which to hang the net. In Ann Huston's (SIT student fall 2008) previous experiment, the main issue with her cages stemmed from their inability to keep *Pomacea canaliculata* contained within the experiment area. Thus, it was proposed to bury the net edges 15 cm into the ground (the depth to which *Pomacea canaliculata* can bury themselves). Once again, this plan changed during the cage construction, when it was suggested that the net need not be buried to such depths. Instead, sharp wooden sticks approximately 10 cm in length and 1 cm in diameter were used every 20 cm along the edge of the net to create a seal between the net and the ground.

Another difficulty that was encountered with the cage design stemmed from the desire to have a netted roof to the cage. To do this, excess net was bunched at the center of the cage and tied into a knot. This knot was large and heavy, blocking sunlight and dipping into the vegetation of many cages. A final note to mention is that during the construction process, much of the area within the cages was walked upon. Vegetation was pushed down into mud, which was in turn artificially packed down. To summarize the difficulties with cage design:

- Support poles located within experiment area
- Netting wasn't buried on edges of experiment area, pushed into the ground with small sticks
- Excess netting was knotted on top, creating artificial shade and dipping into vegetation of experiment area
- Experiment area was walked upon during set-up

Figure 1. Example of Completed Cage

3.1.2 Vegetation Damage

One of the most important but difficult variables to quantitatively measure was the vegetation damage caused by different densities of *Pomacea canaliculata*. Not only was it probable that the cage design contributed to significant plant damage, but judging whether a plant had been eaten by *Pomacea canaliculata* proved to be subjective. Evidence such as yellow browning grass or cut stalks could be contributed to snails, but this damage has only been observed with rice farm species and not the local vegetation being examined for this experiment.

3.1.3 Equipment

Some of the equipment used in this experiment was not suited for the environment of Tram Chim National Park. The Hanna instruments used to measure nitrate, phosphate, and iron levels use light to measure the concentration of the respective molecules within sample water. Due to high levels of plant life within the water, it was often very difficult to find a water sample that the Hanna instruments were able to use. Furthermore, consciously attempting to gather water samples that had very little vegetation within them brought about further bias.

Each Hanna instrument carries with it a parameter for levels of respective molecules that they are able to measure. Each reader, time after time, gave flashing readings of 0.00 or 2.75, the maximum and minimum levels that they measure. These readings can be used as valued data, but they are hardly an exact reading that any scientist would prefer.

3.1.4 Holiday

Sometimes, even the culture of a people or country can effect the success of a field run experiment. The *Pomacea canaliculata* cages were installed in Tram Chim National Park on April 23, 2009 (Day 0). For a period of 14 days, each cage was to be visited and analyzed every two days. However, with Labor Day and Reunification Day holidays on May 1st and 2nd, there was no staff available in Tram Chim National Park to assist in data gathering on Day 10 (May 3rd, 2009). Thus, it was decided that rather than skew the data entry collection periods by gathering data on the 3rd day, the next data was not recorded until Day 12 (May 5th, 2009).

3.1.5 Water Buffalo

In Tram Chim National Park, water buffalo are not allowed. Neither are fish nets, lizard traps, or local villagers. And yet, all have still managed to make a presence within the park's boundaries. Even some of the rangers own water buffalo and allow them a certain breadth of travel within zone A1. On Day 2 (April 25th, 2009) of the experiment, it was discovered that water buffalo had trampled all the cages of *Oryza rufipogon.* All cages except for the 8 snail count cage were torn in several locations. The vegetation itself was also heavily damaged in each observation area and an undetermined number of snails had escaped from the 16 count and 24 count cages.

In order to still be able to procure data on *Oryza rufipogon*, it was decided that the 8 snail count cage would be salvaged and two new cages would be installed. Since the 8 snail count cage only showed signs of having been pushed over (but not torn or uprooted), this cage was erected in the same location. A new 16 snail count cage was constructed in an undamaged location with new *Pomacea canaliculata*. A new control area was also outlined.

Figure 2. Cage Destroyed by Water Buffalo

3.1.6 Villagers

Tram Chim National Park has a very difficult relationship with the villagers surrounding its borders. The protectionist approach of the park has excluded villagers from any legal resource use or management within its boundaries (Thien, 2009). In the past, this resentment has realized itself in the form of armed confrontation and arson. Although it was unclear whether the motives for villagers stealing *Pomacea canaliculata* experiment cages was spite or simply the desire for useful netting (or both), villagers of Tram Chim had a significant impact on the success of this experiment.

On Day 6 (April 29, 2009), two *Pomacea canaliculata* cages were stolen. The netting for *Eleocharis dulcis* 8 snail count and *Oryza rufipogon* 16 snail count had disappeared. The area from which these nets were stolen contained 15 total *Pomacea canaliculata* cages (including un-netted controls), but only these two were missing. It was decided to continue with data gathering and accept the premature and incomplete conclusion of those two cage experiments.

On Day 12 (May 5, 2009), the 9 remaining netted cages were stolen from the experiment zone containing all cages for *Eleocharis dulcis*, *Eleocharis atropurpurea*, *Oryza rufipogon*, and *Melaleuca cajuputi*. *Pomacea canaliculata* had left the cage areas and, despite efforts, were not found in the surrounding area in any significant numbers.

Figure 3. Cage Area after Stolen Net

3.2 Note on Data Results

With the knowledge of some of the difficulties encountered throughout the experiment process, it is now possible for the reader to be able to meaningfully interpret the gathered data. The data gathered throughout this project is valuable data, but it should be noted that any data is only as strong as its consistency and scale.

Field work is a process. Sometimes there are breakthroughs that allow for rapid headway, while other times the stagnancy can be almost stifling. This experiment provided some of the former and a large amount of the latter. In an effort to be as scientific as possible in publishing results, there will be no effort to make more of this experiment than it actually was. Where gaps in data exist, areas will be left blank so as to provide guidance on how the project could be replicated within the future. Data drawn from malfunctioning equipment will also be shown, so as to be able to support the inconsistency in readings.

The original purpose of this experiment was to study the effect of *Pomacea canaliculata* on *Eleocharis atropurpurea*, *Panicum repens, Eleocharis dulcis*, *Melaleuca cajuputi*, and *Oryza rufipogon*. However, due to unforeseen difficulties and the inability to gather certain conclusive evidence (stem count, vegetation damage, snail weight change), it became easier to instead study the two following questions:

1. Within *Eleocharis atropurpurea*, *Panicum repens, Eleocharis dulcis*, *Melaleuca cajuputi*, and *Oryza rufipogon* habitats, where and to what extent will different densities of *Pomacea canaliculata* be able to reproduce?

2. Within *Eleocharis atropurpurea*, *Panicum repens, Eleocharis dulcis*, *Melaleuca cajuputi*, and *Oryza rufipogon* habitats, in what ways do different densities of *Pomacea canaliculata* affect the natural environment of each habitat?

With these two questions in mind, the following list of results seeks to compile and examine gathered data in such a way as to provide a foundation from which to create an empirically sound conclusion.

3.3 *Eleocharis Atropurpurea*

Tests performed on *Pomacea canaliculata* in *Eleocharis atropurpurea* cages showed differing densities of *Pomacea canaliculata* had little effect on the pH, electrical conductivity (EC), and dissolved oxygen levels. As Figure 4 and Figure 5 show, the variance for both pH levels and electrical conductivity levels is minimal. Figure 6 depicts a significant change in dissolved oxygen levels, but that change is constant for all cages containing different densities of *Pomacea canaliculata*.

The data collected by Hanna Instruments (Nitrate, Phosphate, and Iron) is sporadic and inconclusive. Please see appendix entries B.1 through B.4 for more details concerning this data.

Eleocharis atropurpurea provided a habitat in which *Pomacea canaliculata* was able to live and reproduce. Figure 7 shows that all densities of *Pomacea canaliculata* reproduced. Rates of reproduction increased as the density of snails increased, culminating with a reproduction rate of just over 5 egg clusters per day for the 24 snail count cage. Discrepancy exists within the 8 snail count cage, when the number of total egg clusters decreases from 9 to 3 between day 4 and day 6.

Regardless, the data gathered from the 16 snail count and 24 snail count cages provides quantitative evidence of *Pomacea canaliculata*'s ability to survive and reproduce within *Eleocharis atropurpurea* vegetation. It should be noted, however, that *Pomacea canaliculata* relied heavily on the cage structure for its egg sack placement. Figure 8 shows that only 5% of all egg clusters were laid upon *Eleocharis atropurpurea* itself. For full details of egg cluster counts, including egg cluster locations within each cage, please refer to appendix entries B.1 through B.4.

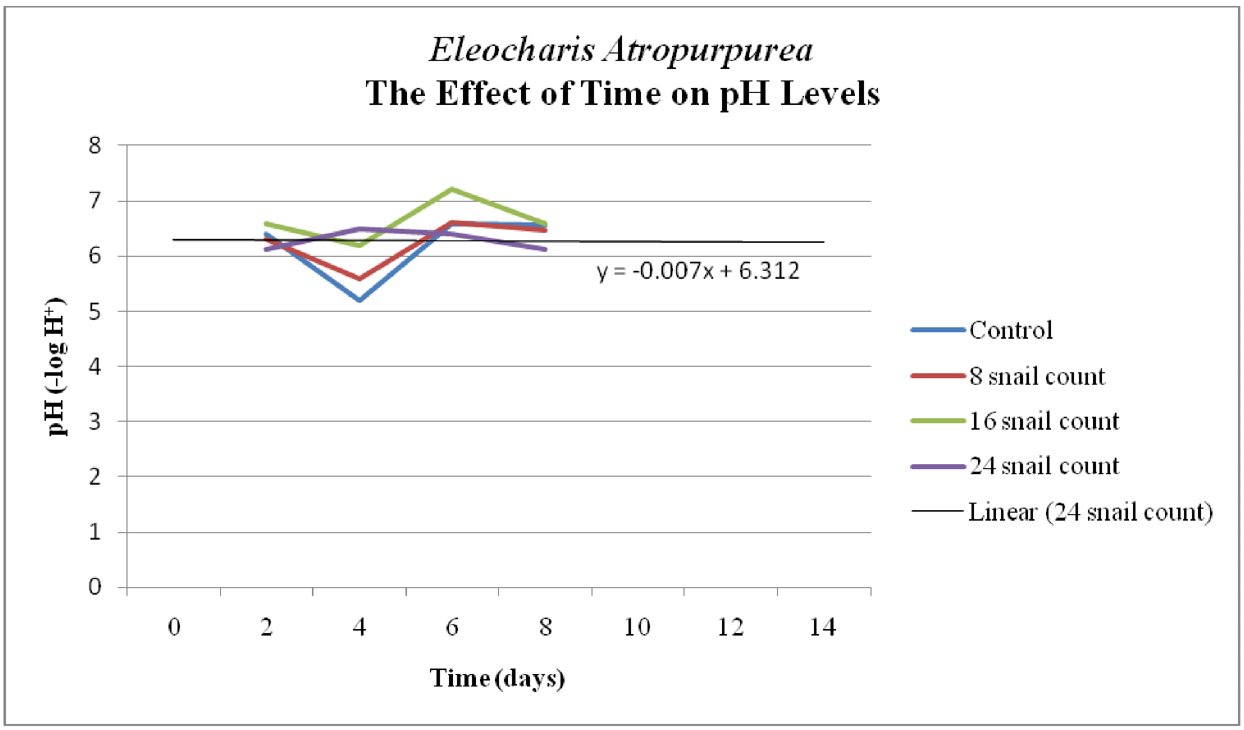


Figure 4. *E. Atropurpurea* - pH

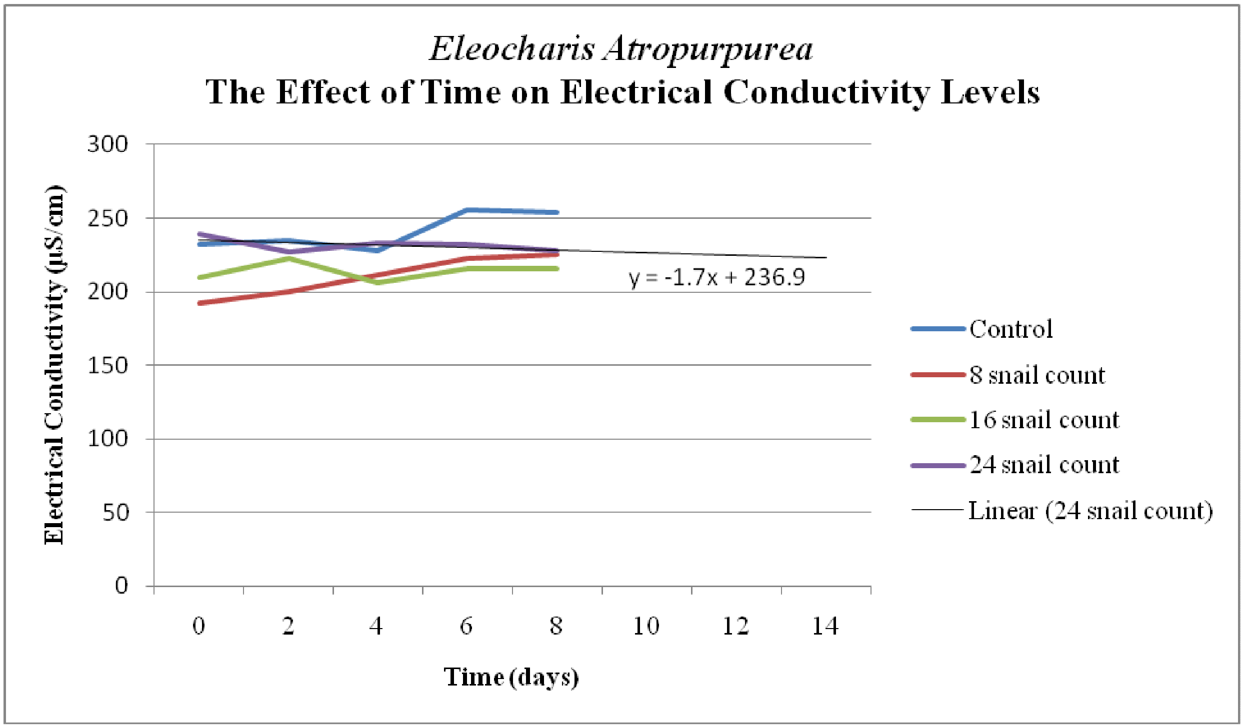


Figure 5. *E. Atropurpurea* - Electrical Conductivity

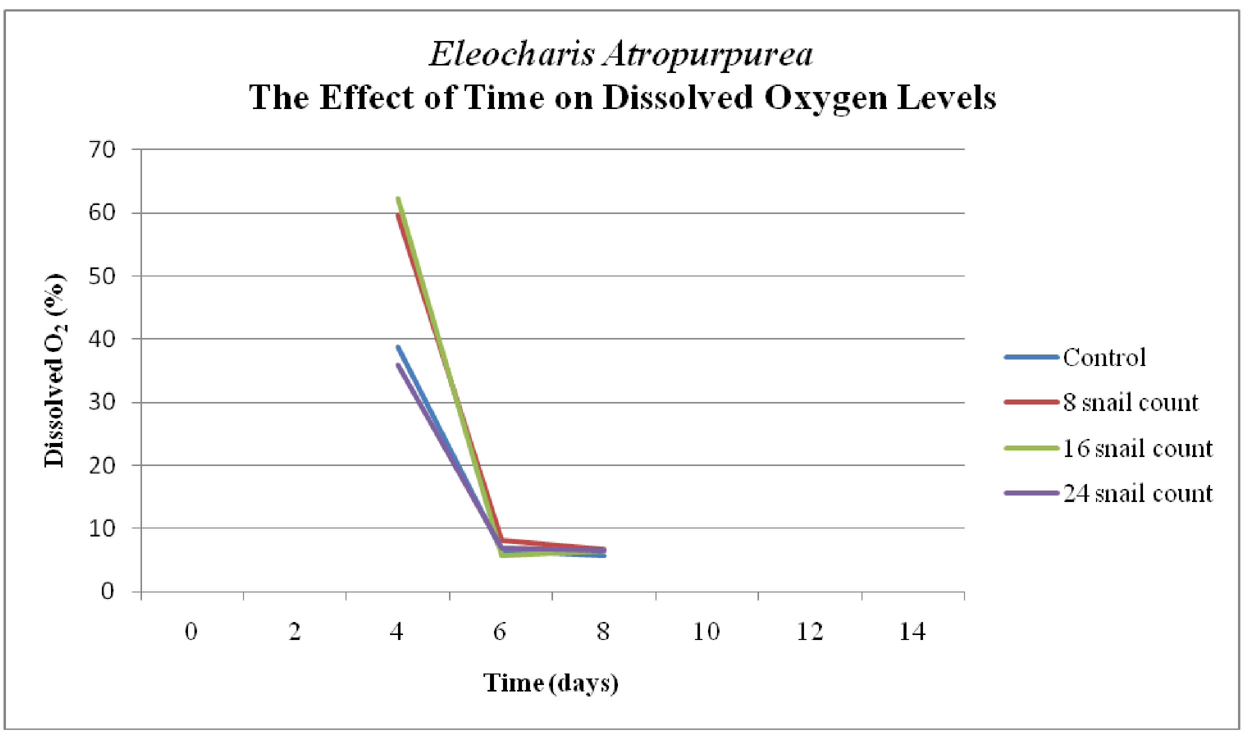


Figure 6. *E. Atropurpurea* - Dissolved Oxygen

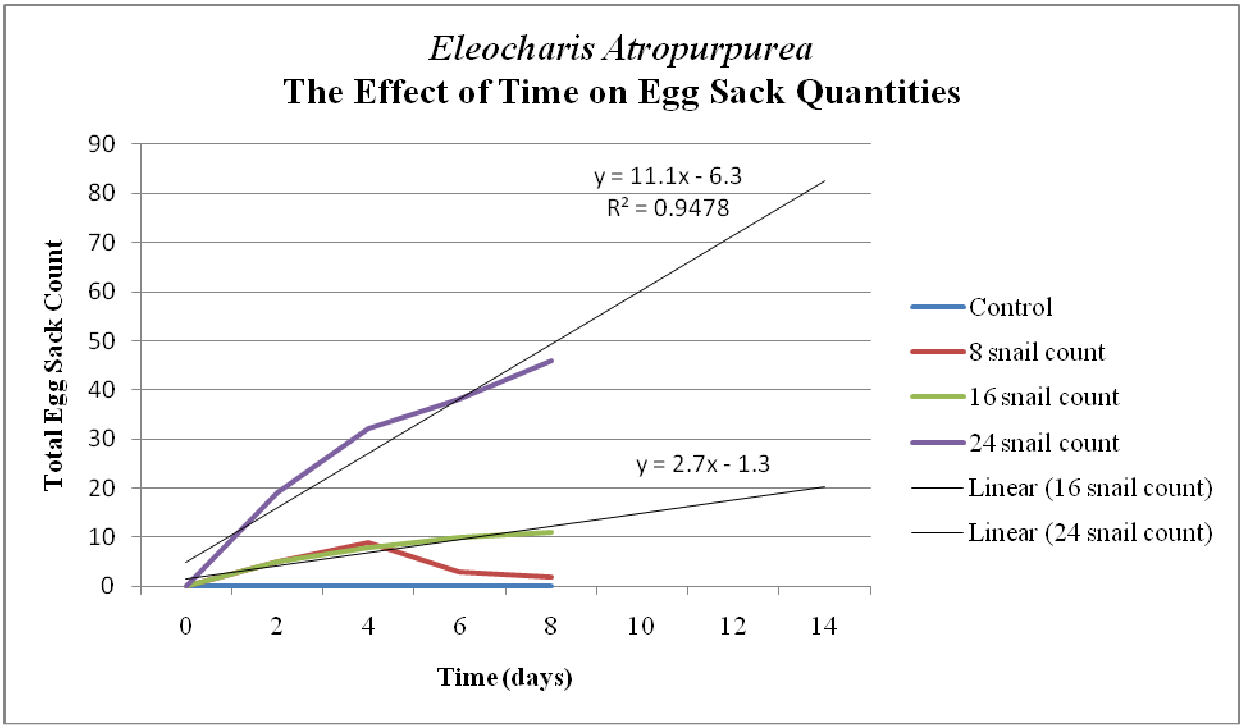


Figure 7. *E. Atropurpurea* - Egg Sack Quantities

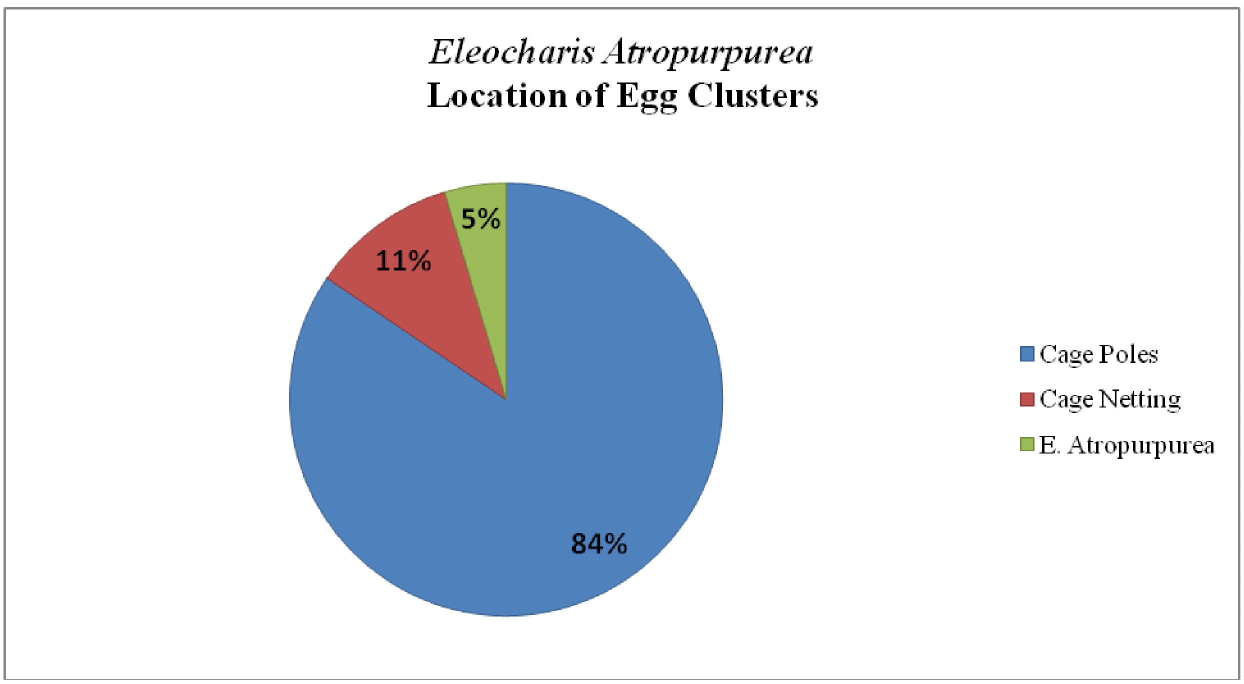


Figure 8. *E. Atropurpurea* - Egg Sack Locations

3.4 *Panicum Repens*

Panicum repens suffered early on in the experiment, when the netting of the 16 snail count cage was stolen between day 4 and day 6 of the experiment. Furthermore, data collected with Hanna Instruments on nitrate, phosphate, and iron levels once again proved too erratic to be able to graph or draw any sort of conclusions from. To view the raw data gathered on these measurements, refer to section C of the appendix.

The data for the pH of the *Panicum repens* cages further supports the result that *Pomacea canaliculata* does not affect the pH levels. As shown in Figure 9, all cages follow the same trend, regardless of snail density.

Just as the levels of dissolved oxygen decreased drastically for *Eleocharis atropurpurea* on day 6 of the experiment, the same pattern occurred in the data collection for *Panicum repens*.

All *Pomacea canaliculata* cages within *Panicum repens* proved capable of supporting snail reproduction. The 8 snail count cage produced egg clusters at an average rate of 1.1 egg clusters per day. Although data collection ended prematurely, the 16 snail count cage produced approximately 1.25 egg clusters per day. The 24 count cage produced a constant average of 5 egg clusters per day.

Figure 13 shows that despite the presence of cage poles and netting, *Pomacea canaliculata* laid egg clusters on *Panicum repens* 51% of the time. Egg clusters were laid on poles 37% of the time and netting 12% of the time.

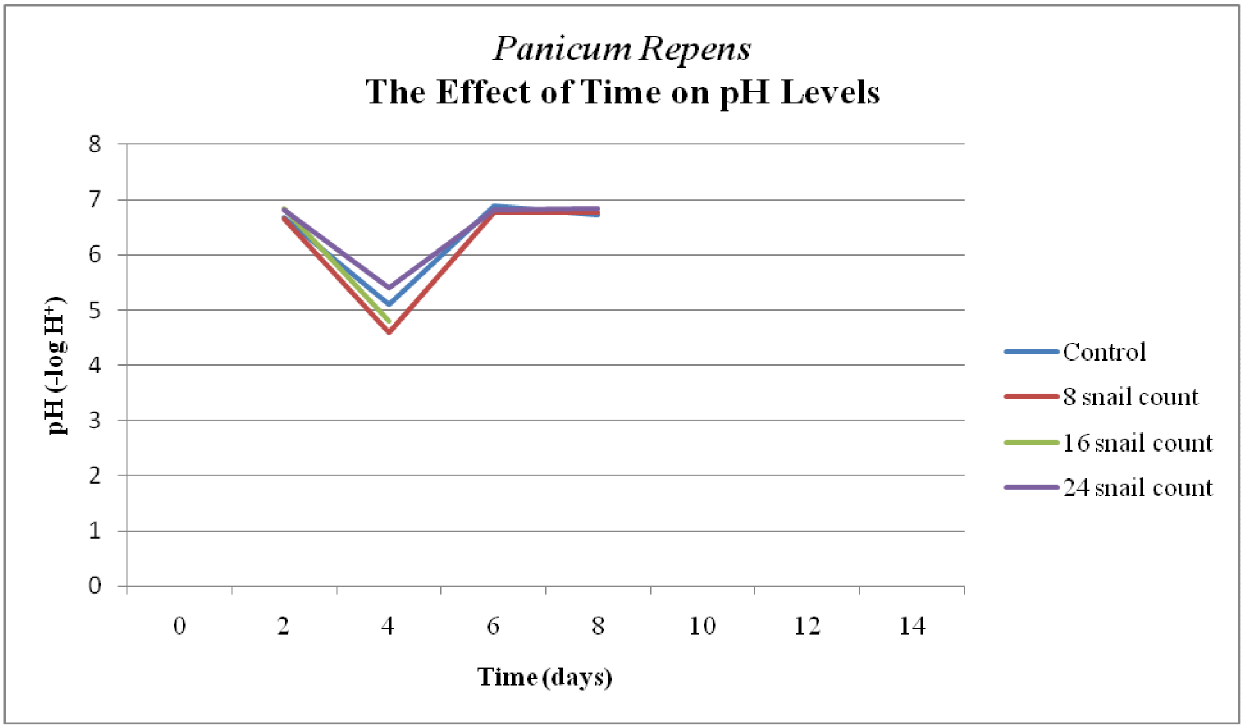


Figure 9. *Panicum Repens* - pH

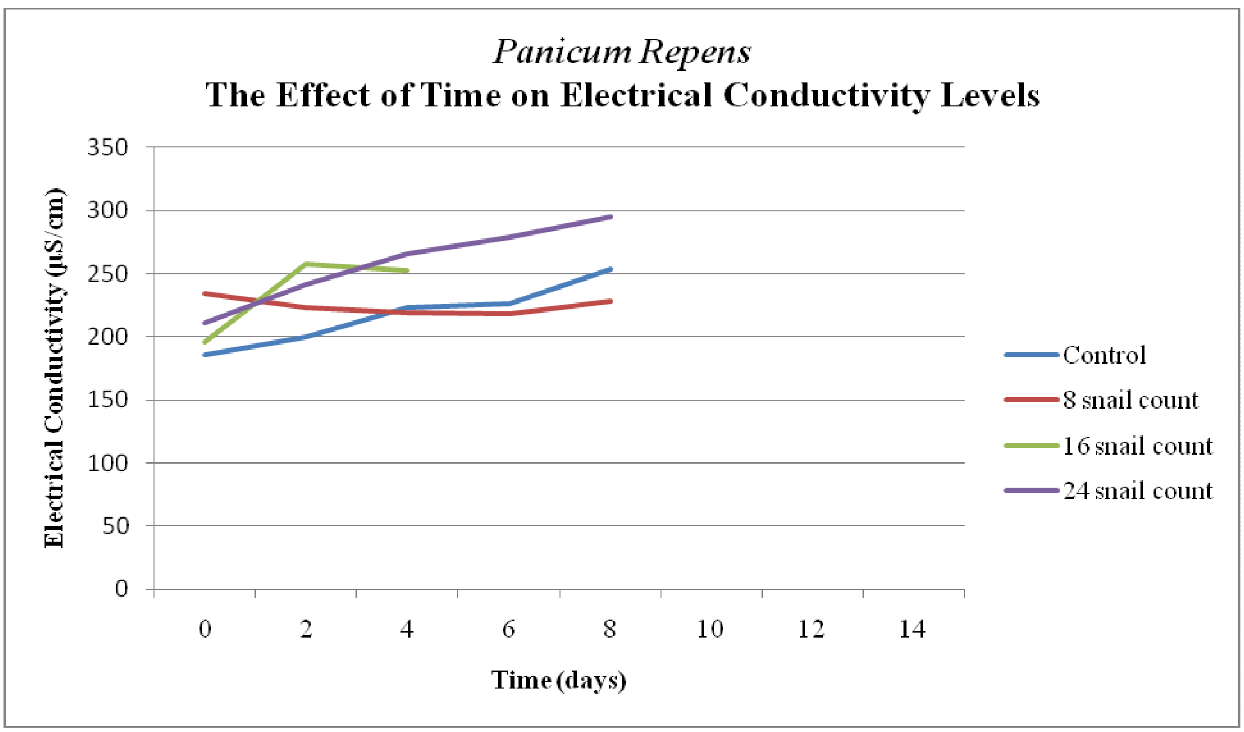


Figure 10. *Panicum Repens* - Electrical Conductivity

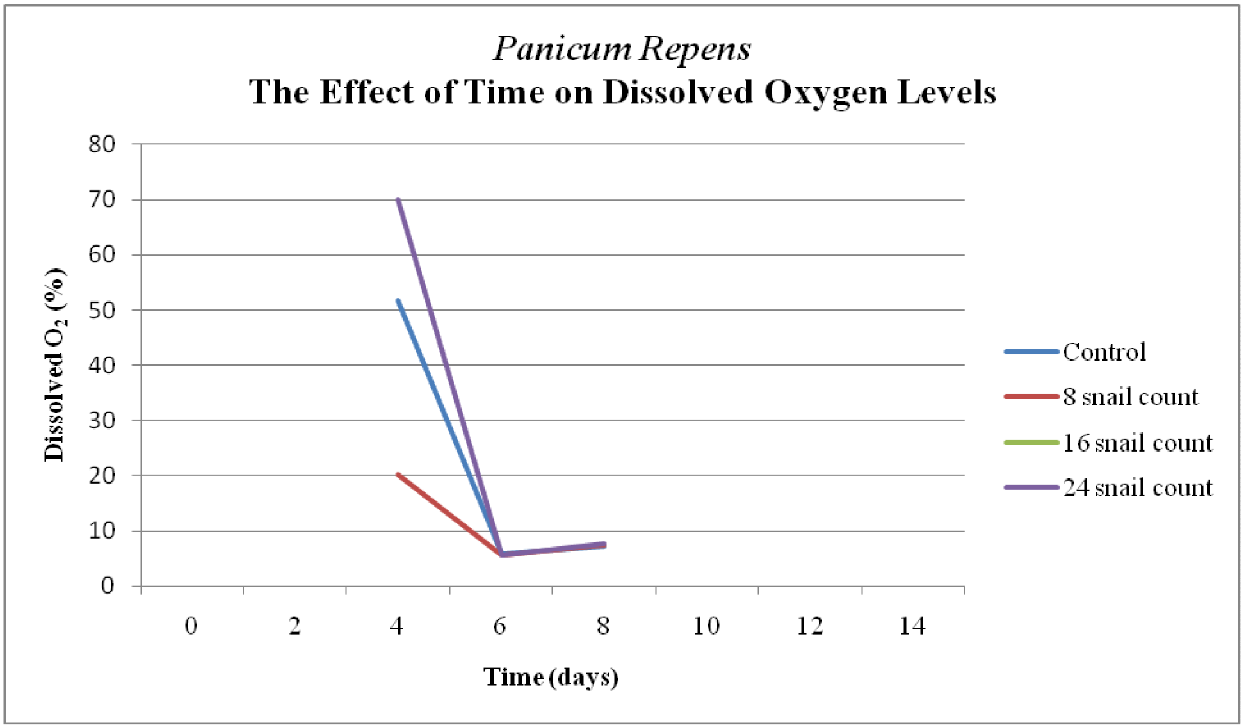


Figure 11. *Panicum Repens* - Dissolved Oxygen

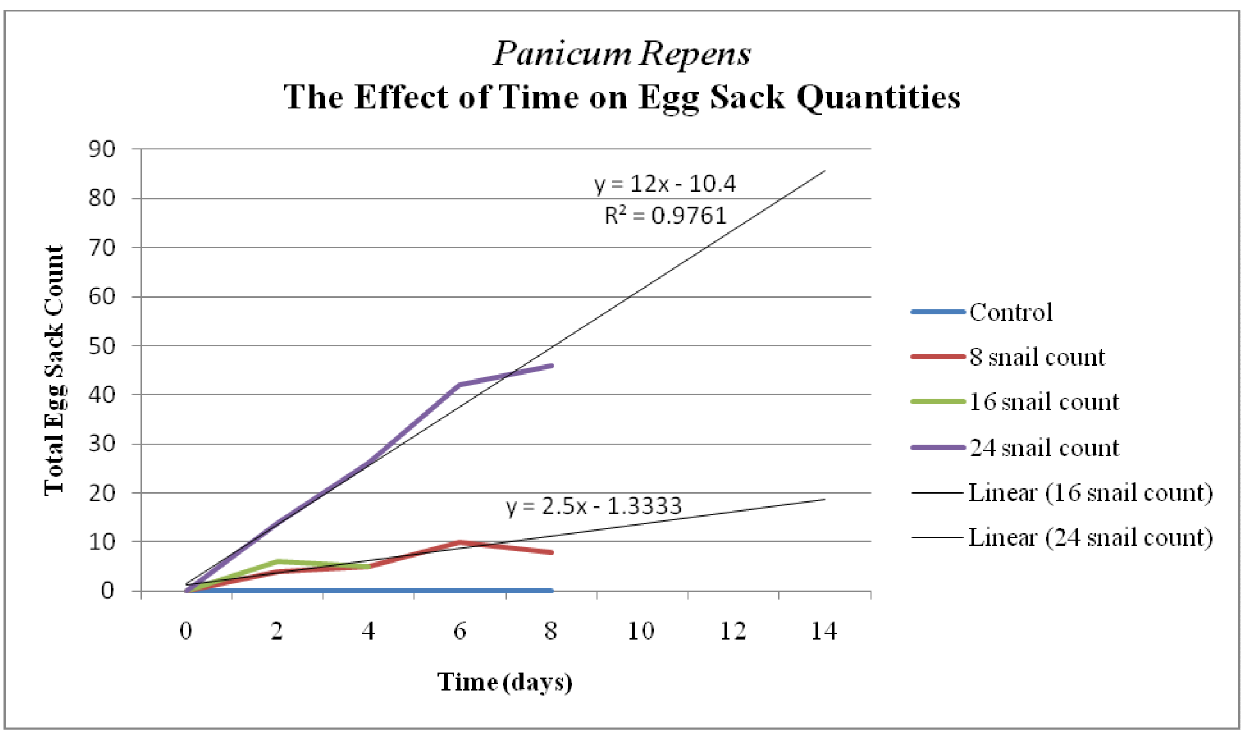


Figure 12. *Panicum Repens* - Egg Sack Quantities

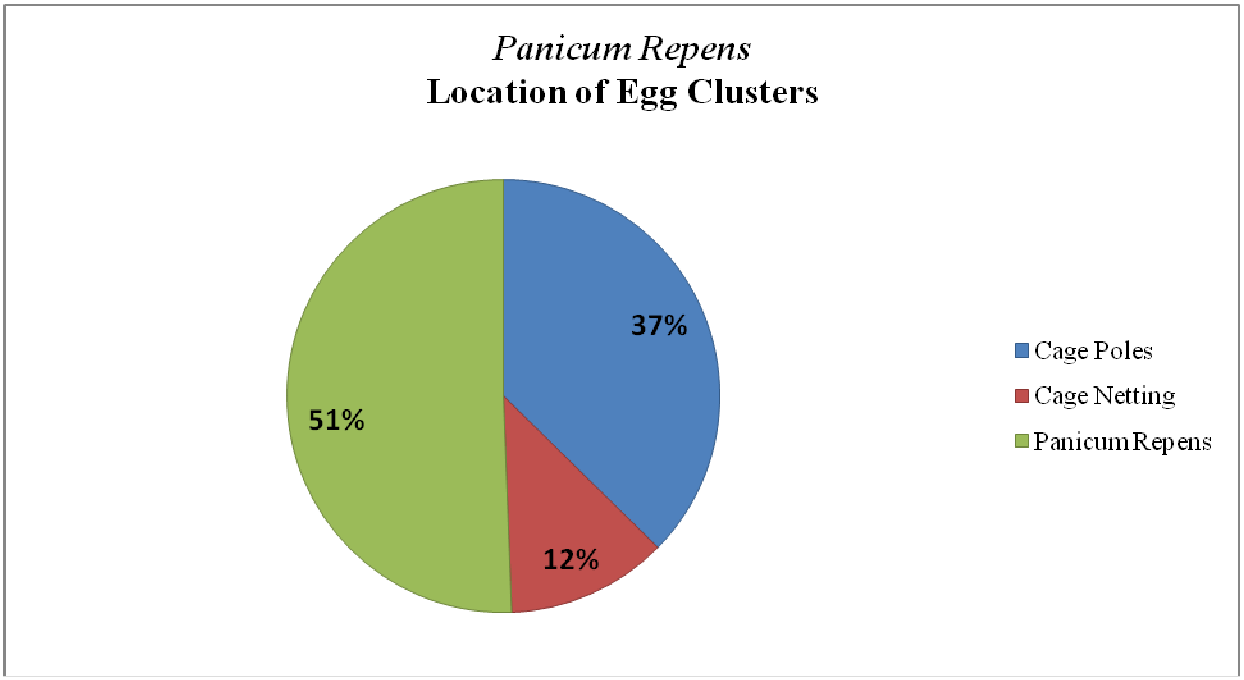


Figure 13. *Panicum Repens* - Egg Sack Locations

3.5 *Eleocharis dulcis*

As shown in Figure 14, different densities of *Pomacea canaliculata* had little to no effect on the pH levels of the *Eleocharis dulcis* cages. At its point of greatest difference on Day 6, the difference between the control pH level (6.17) and 16 snail count cage (6.7) was only 0.53.

The electrical conductivity data measurements show that, at most, there is a difference of 50 µS/cm between the control, the 16 snail count cage, and the 24 snail count cage. Between day 2 and day 6 of the experiment, the 16 count cage and 24 count cage followed nearly opposite patterns.

Just as with electrical conductivity, there was no great variance amongst the cages in terms of dissolved oxygen content. For the three days of measurement that were possible, the 24 snail count cage remained at a fairly constant 4% higher than the control. During the same period, the 16 snail count cage remained at a fairly constant 4% below the control. On the last day of observation, day 8, all cages converged at an approximate dissolved oxygen level of 7%, ± 1%.

The egg sack cluster growth rate for *Pomacea canaliculata* in *Eleocharis dulcis* was constant for both the 16 snail count cage and the 24 count cage. The 16 count cage had a growth rate of 2.95 egg clusters per day, while the 24 count cage had a growth rate of 2.45 egg clusters per day. No data could be taken on the 8 snail count cage on account of its being stolen after the second round of observations.

In the *Eleocharis dulcis* cages, *Pomacea canaliculata* tended to prefer cage poles as the laying ground for egg clusters. 59% of all egg sacks were laid on cage poles, 39% on *Eleocharis dulcis*, and only 2% on the cage netting itself.

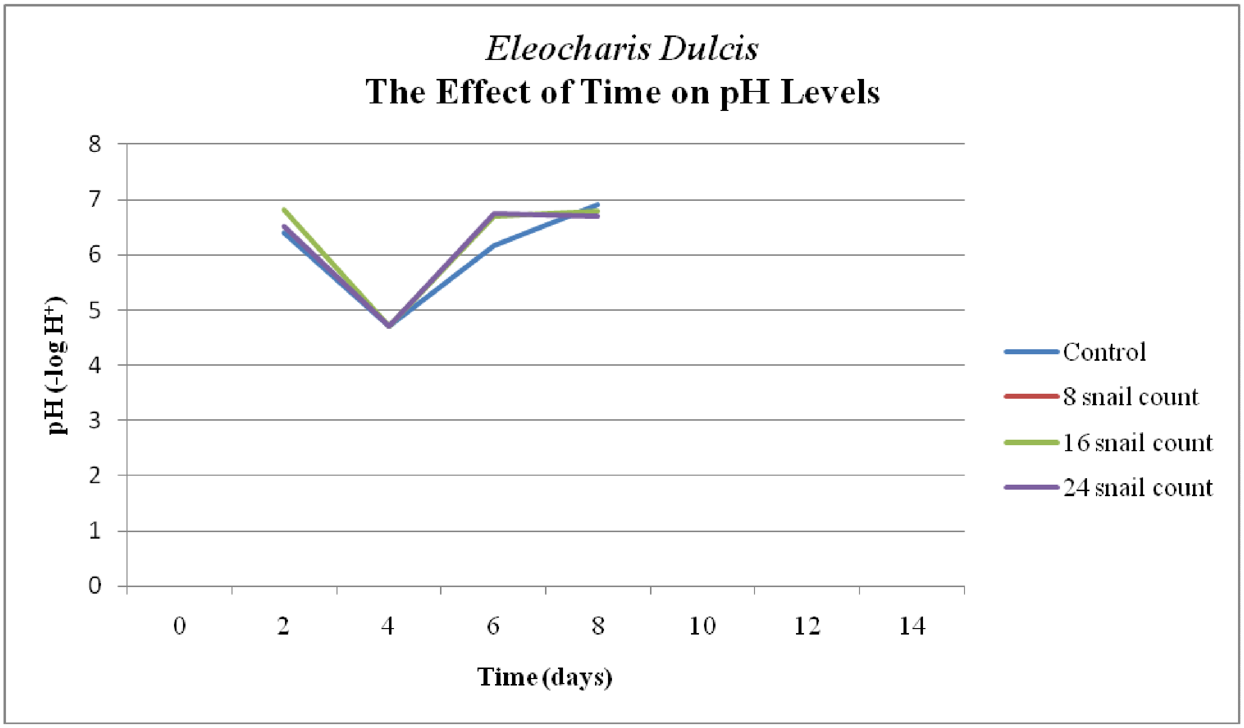


Figure 14. *E. Dulcis* - pH

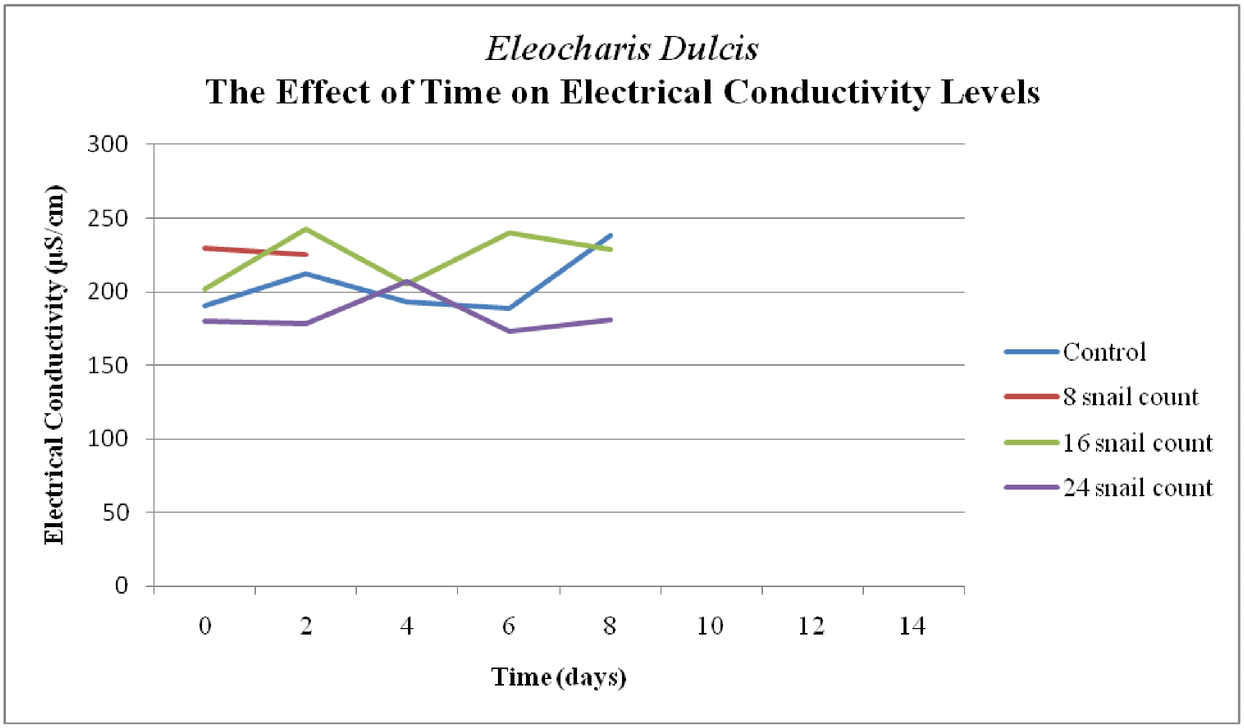


Figure 15. *E. Dulcis* - Electrical Conductivity

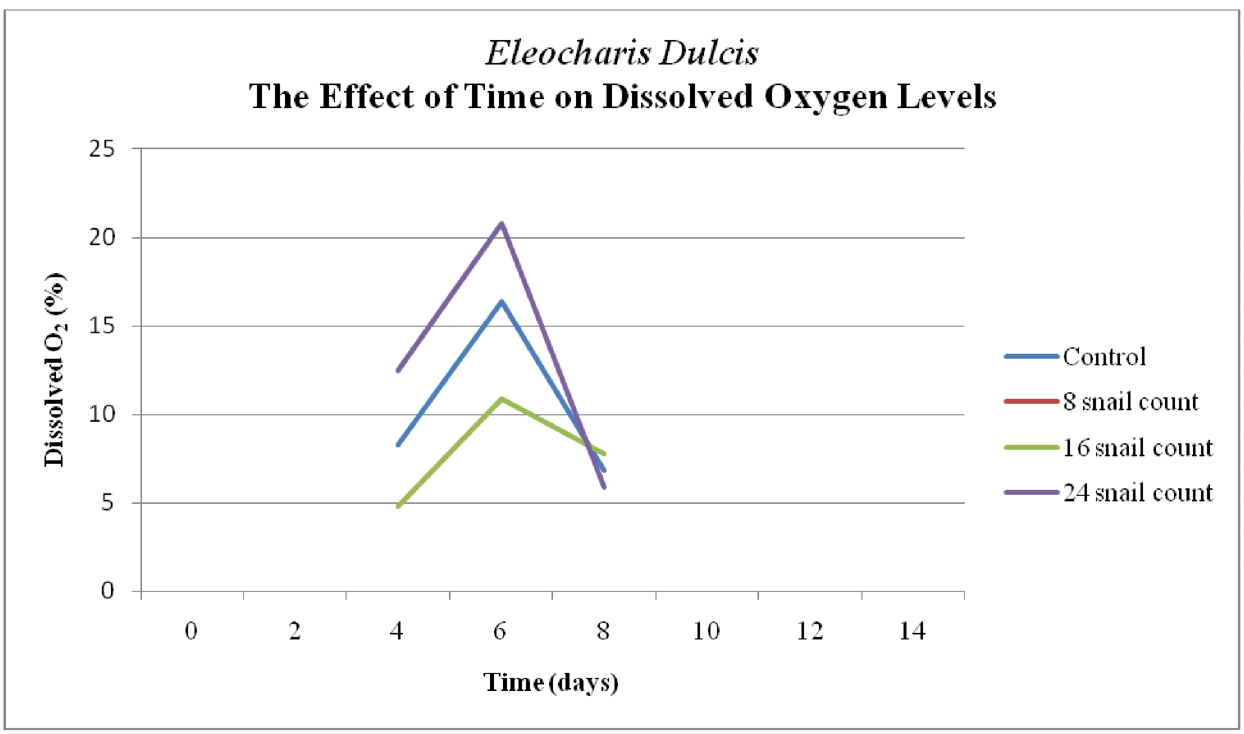


Figure 16. *E. Dulcis* - Dissolved Oxygen

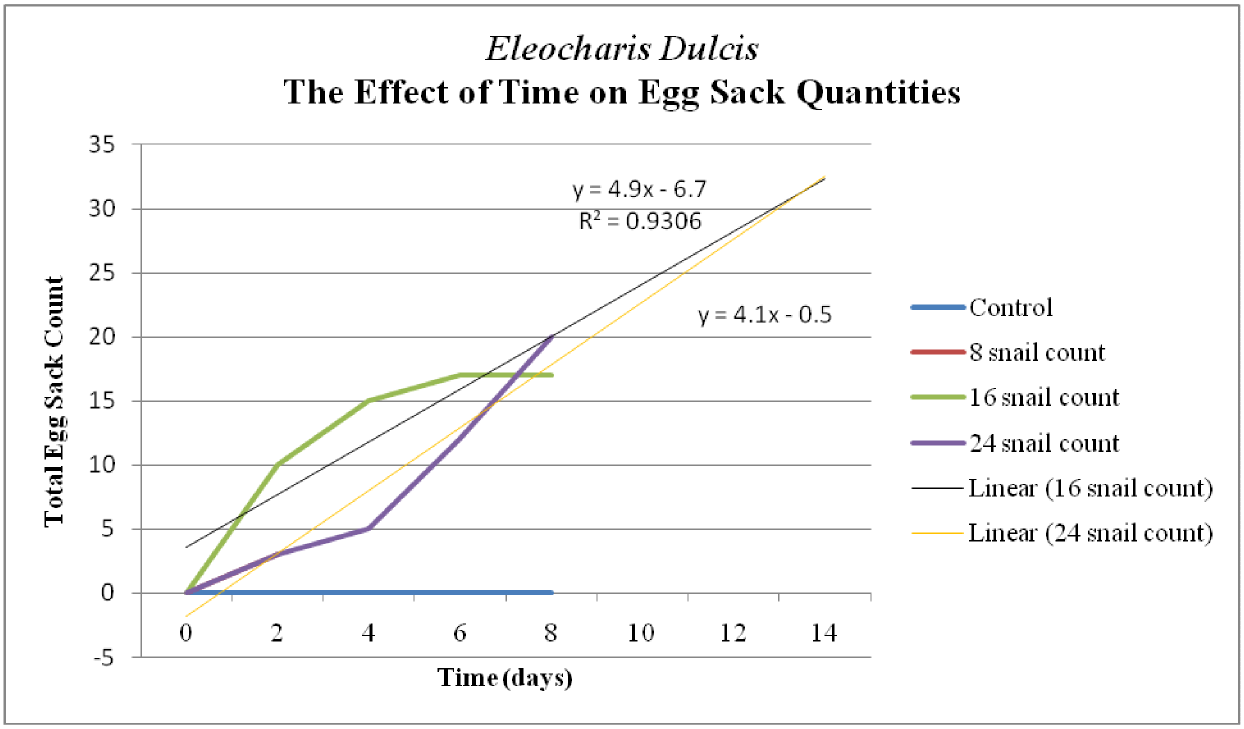


Figure 17. *E. Dulcis* - Egg Sack Quantities

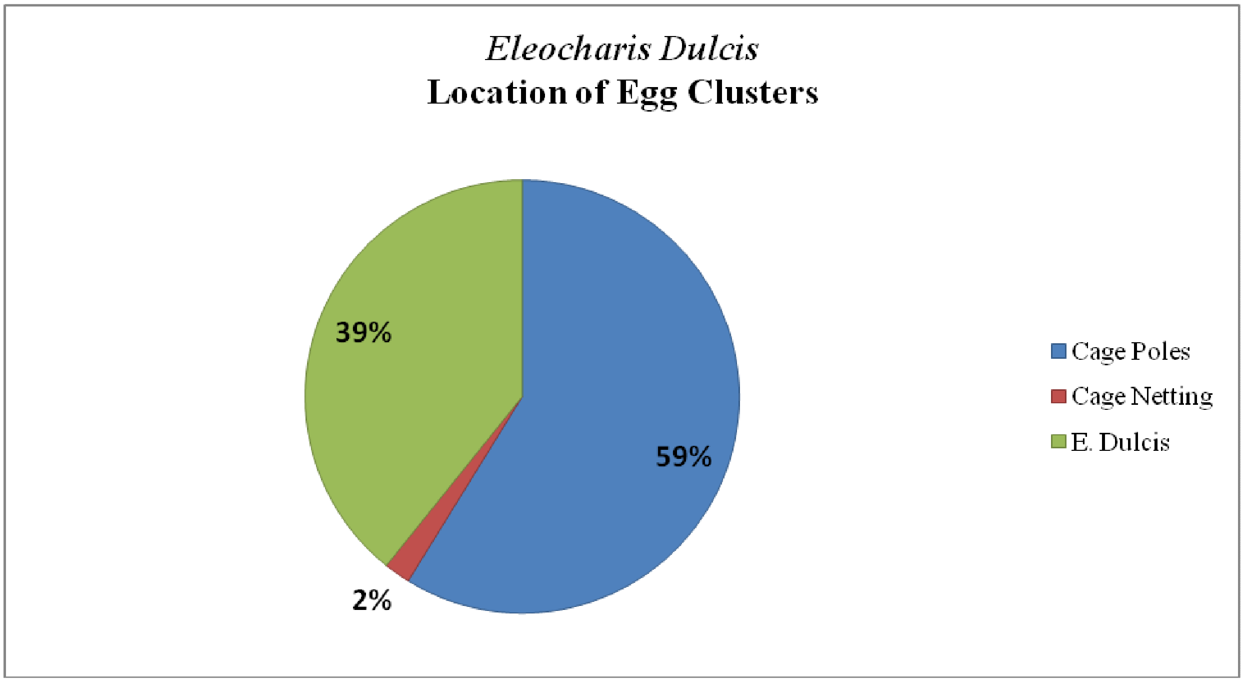


Figure 18. *E. Dulcis* - Egg Sack Locations

3.6 *Melaleuca Cajuputi*

Once again, data collected using Hanna Instruments was not examinable and are not included in the results question. Please refer to appendix E.1 through E.4 to view this data.

The pH level of *Melaleuca cajuputi* cages showed no direct correlation with the different densities of *Pomacea canaliculata*. Each cage followed the same overall trend, starting at pH 6.5, decreasing to a pH of 4 to 5, and then increasing once again to a pH of 6.5.

Electrical conductivity for all cages increased by 50 to 100 µs/cm over the course of the data collection period. The cages followed a steady upwards trend. The lesser the snail density, the more extreme the change in electrical conductivity, although no extrapolations should be made from this observation.

The dissolved oxygen content for *Melaleuca cajuputi* cages did not change depending on the density of *Pomacea canaliculata*. As was the case for *Eleocharis atropurpurea*, *Panicum repens*, and *Eleocharis dulcis*, dissolved oxygen decreased between day and day 6. From day 6 to day 8, change in dissolved oxygen was minimal, differing in direction depending upon the cage.

As shown in Figure 22, *Melaleuca cajuputi* provided a habit in which *Pomacea canaliculata* could reproduce. The 8 snail count cage produced egg sack clusters at an approximate rate of 1.15 clusters per day. Snails within the 16 count cage produced egg sack clusters at an approximate rate of 2.15 snail clusters per day. The 24 count cage had the highest rate of production with an average of 5.3 egg sack clusters produced per day.

Melaleuca cajuputi was the preferred egg cluster laying ground, as shown in Figure 23. 72% of all egg sack clusters were located on *Melaleuca cajuputi*. 25% were laid on cage poles and the remaining 3% of egg clusters were laid on cage netting.

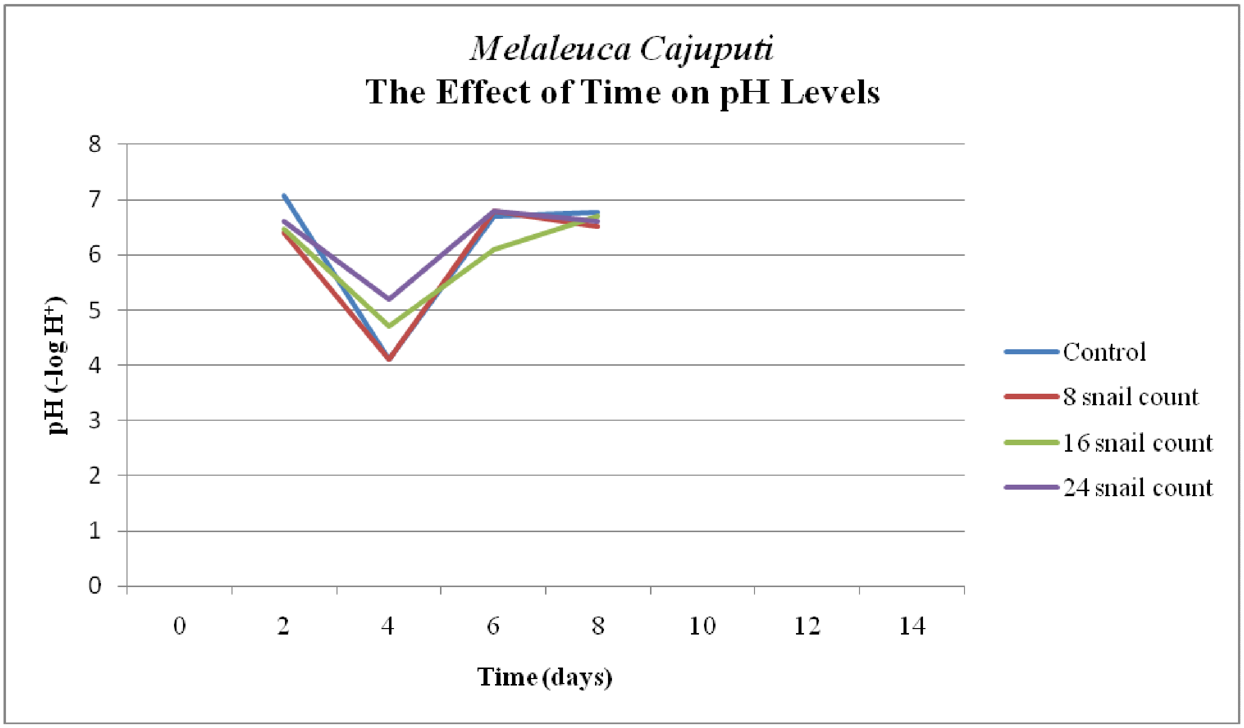


Figure 19. *Melaleuca Cajuputi* – pH

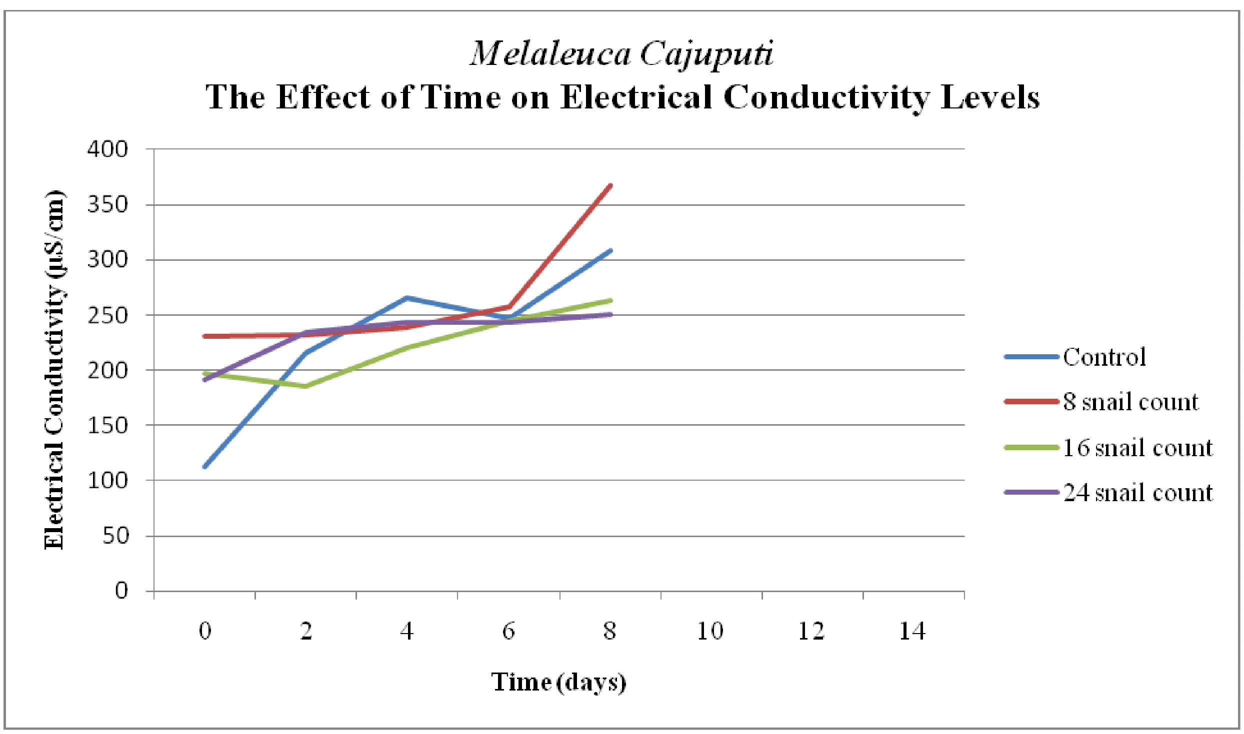


Figure 20. *Melaleuca Cajuputi* - Electrical Conductivity

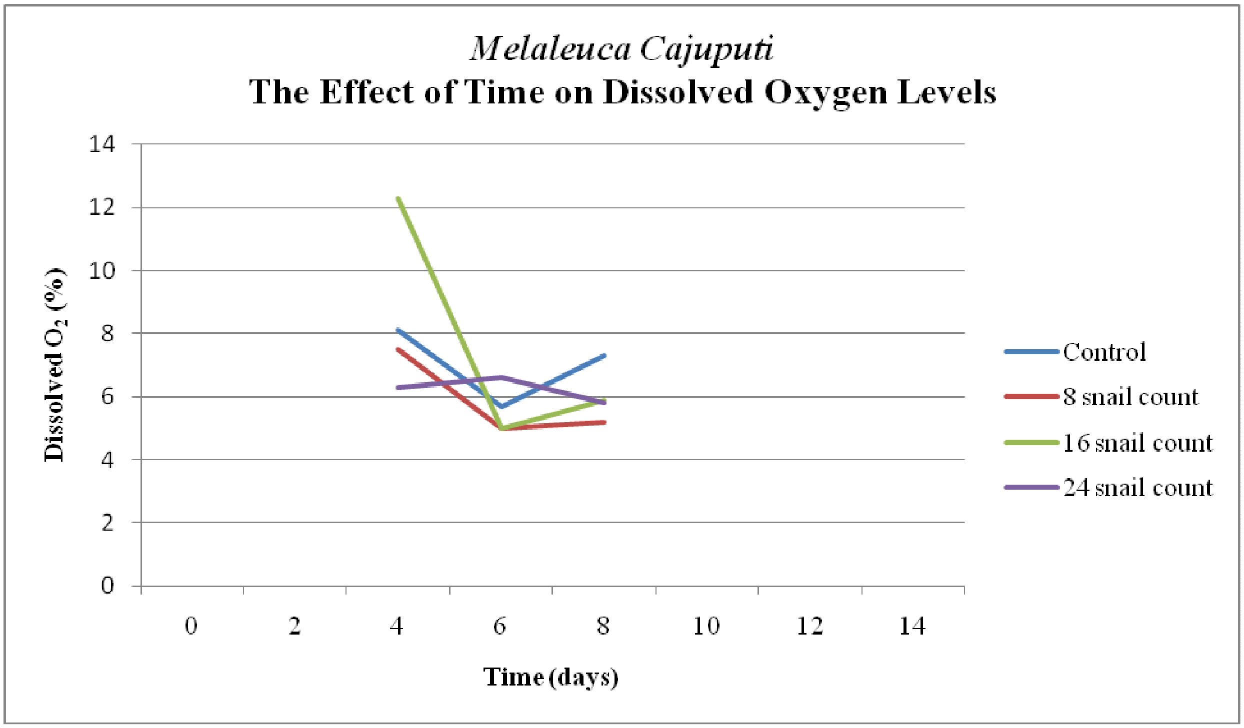


Figure 21. *Melaleuca Cajuputi* - Dissolved Oxygen

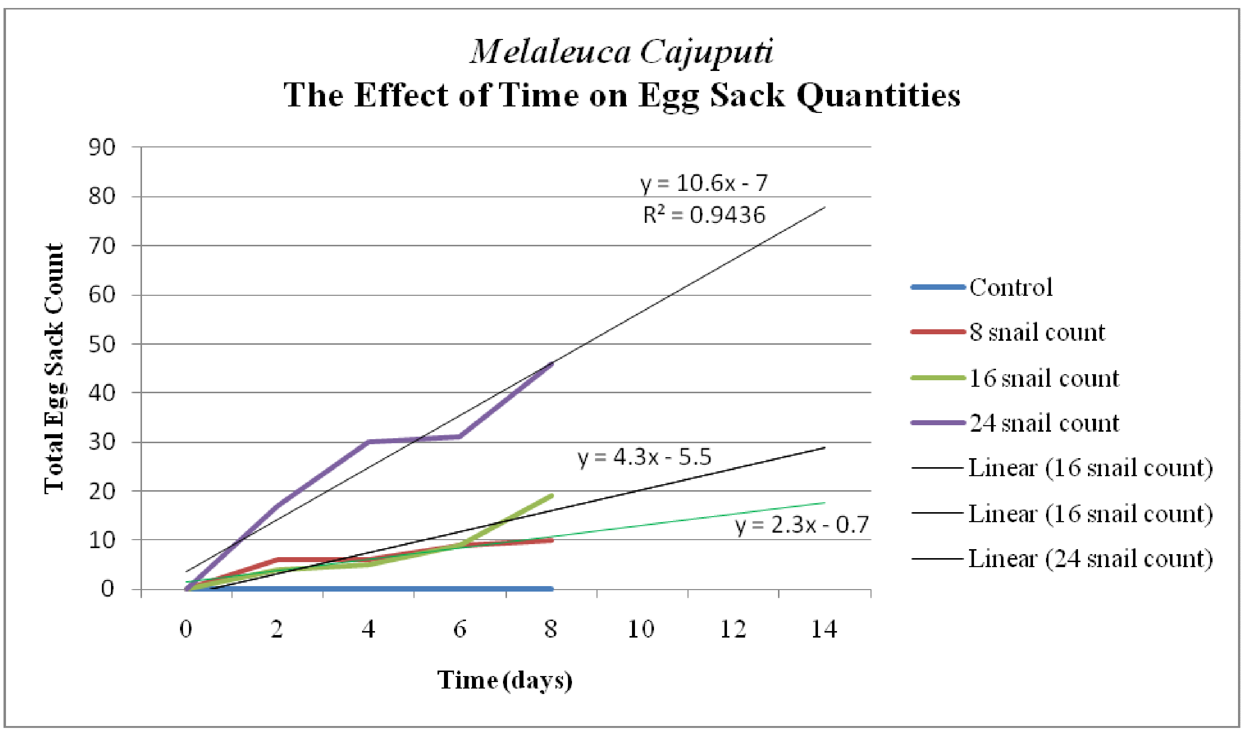


Figure 22. *Melaleuca Cajuputi* - Egg Sack Quantities

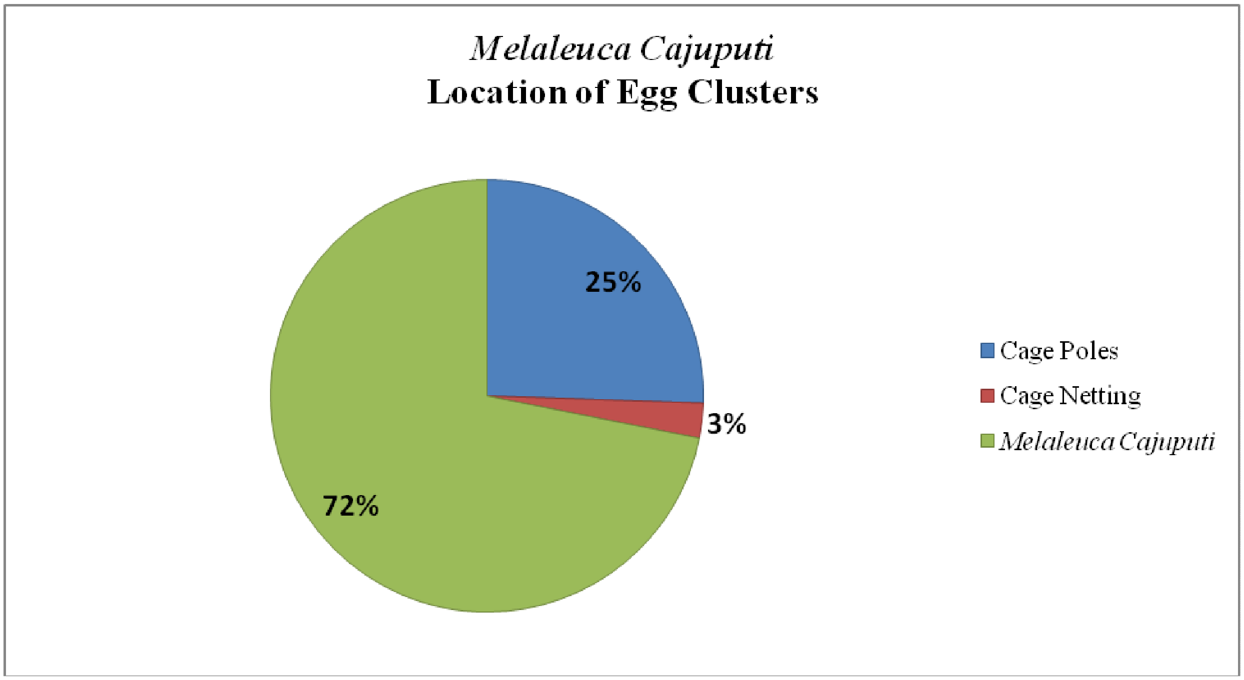


Figure 23. *Melaleuca Cajuputi* - Egg Sack Locations

3.7 *Oryza Rufipogon*

By far the most challenging species from which to create results, *Oryza rufipogon* became a unique data collection case when it was discovered on day 2 that the entire examination area had been trampled by water buffalo.

Every cage within the observation area was damaged in one way or another. In an effort to create useable data, the following steps were taken:

- The control cage was repositioned in a new, undamaged area of *Oryza rufipogon*.
- The 8 snail count cage was rebuilt. There were no visible holes in the net or openings at the bottom of the net, so it was assumed that the cage had remained sealed, besides being pushed over.
- The 16 snail count cage was moved to a new location where a new experiment could be started. On day 4 of the overall project, 16 new snails were added to this cage and observation began again.
- The 24 snail count cage was abandoned. The netting was ripped beyond repair.

As more days went by and more data was gathered, it became evident that several problems still existed with the examination of *Oryza rufipogon*. The 16 snail count cage produced only 1 egg sack cluster over the following 8 days. Although the control cage and 16 snail count cage had been moved, the entire experiment had been contaminated in one way or another by water buffalo. It was unclear if water buffalo revisited the area, but the lingering effects were obvious. Murky water, trampled vegetation, and water buffalo feces were evident throughout the entire test area.

The data for *Oryza rufipogon* is available in Appendix section F, but will not be converted into graph form in this paper. The inability for comparison combined with the uncertainty of independent variables effecting the *Oryza rufipogon* cages made conclusions for this portion of the experiment very difficult. One area of data that could have remained unaffected by water buffalo is the distribution of *Pomacea canaliculata* egg clusters within each cage. Therefore, Figure 24 has been included to depict the distribution of eggs. 58% of all egg clusters were laid on *Oryza rufipogon*, 42% were laid on cage poles, and just 2% were laid on the cage netting.

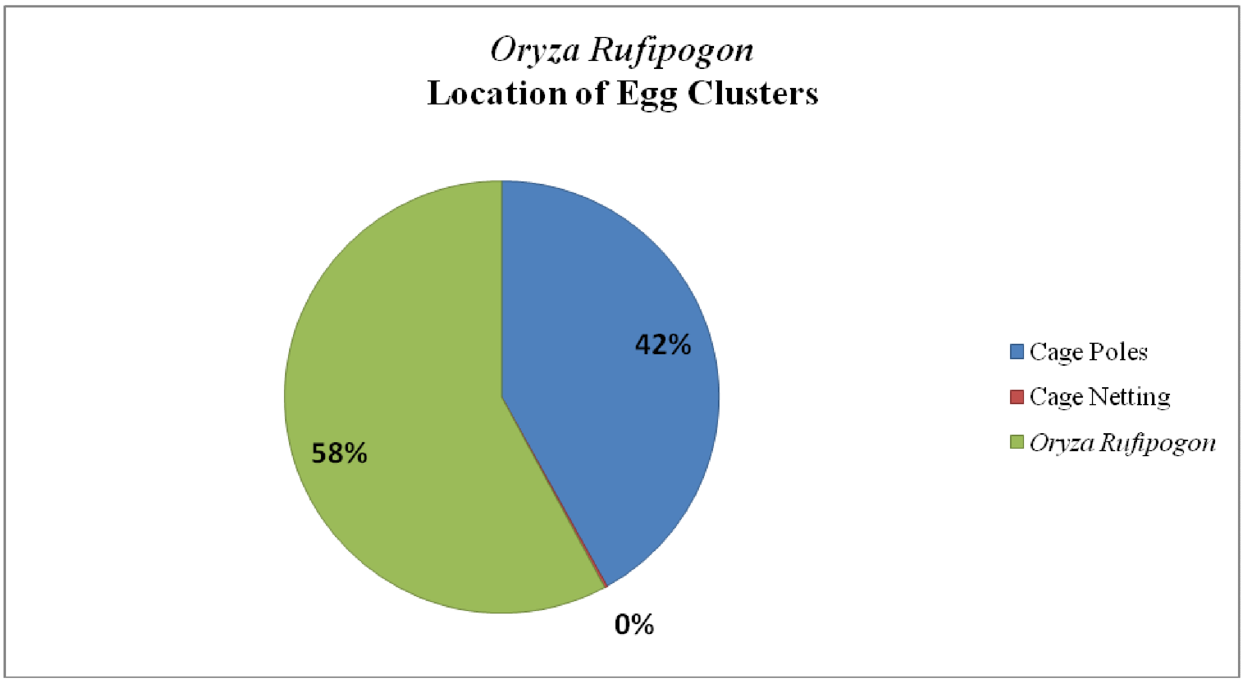


Figure 24. *Oryza Rufipogon* - Egg Sack Locations

4. CONCLUSION

As evidenced from the results section and the appendix, much of the data collected during the course of this experiment remains unreadable. Another large part of the data is useable, but not in a way that allows the original study question to be answered the way it was originally intended to be answered. However, there are conclusions to be gathered from the results of this experiment. These conclusions can be used not only to help gain a better understanding of what aspects of the environment *Pomacea canaliculata* do and do not affect, but also to help guide future research scientists in their efforts to design an efficient and focused experiment at Tram Chim National Park.

The conclusions drawn from this experiment seek to answer the following two study questions:

1. Within *Eleocharis atropurpurea*, *Panicum repens, Eleocharis dulcis*, *Melaleuca cajuputi*, and *Oryza rufipogon* habitats, where and to what extent will different densities of *Pomacea canaliculata* be able to reproduce?

2. Within *Eleocharis atropurpurea*, *Panicum repens, Eleocharis dulcis*, *Melaleuca cajuputi*, and *Oryza rufipogon* habitats, in what ways do different densities of *Pomacea canaliculata* affect the natural environment of each habitat?

In order to make the conclusions to these questions as applicable as possible to Tram Chim National Park, it is necessary to compare the results from all five plant species. What is most important to understand is the overall effect that *Pomacea canaliculata* is having on the park. By examining all plant species together, it will become easier to discern where *Pomacea canaliculata* has the most effect and, subsequently, where it is able to survive and reproduce.

4.1 Conclusion for Study Question 1

In Figure 25, the final total number of egg sack clusters for all cages of each plant species was counted and graphed. From this chart, it becomes evident that, in terms of total egg sack clusters laid in all cages, the quantities had no significant variance. *Eleocharis dulcis* cages produced the least number of egg sacks at 49, while *Melaleuca cajuputi* produced the greatest number of egg sacks at 75.

It makes sense that *Melaleuca cajuputi* produced the greatest number of egg sacks, as this tree provides an optimal laying ground for *Pomacea canaliculata*. Its roots dip into the water, but rise over 50 cm from the water surface. *Pomacea canaliculata* can use these roots to climb up and lay their eggs conveniently and safely approximately 10-20 cm above the waters surface.

While *Eleocharis dulcis* is a sturdy plant that grow to heights of over 30 cm above water level, it should be noted that the *Eleocharis dulcis* within the examination area of this experiment did not provide optimal laying ground for *Pomacea canaliculata* (Ghesquiere, 2001). As is often the case in Tram Chim National Park, strong winds had caused all *Eleocharis dulcis* within the area to be severely bent over at a nearly parallel angle to the ground (Thien, 2009). Thus, a plant that would normally rise high above the water level and provide *Pomacea canaliculata* with egg sack laying area became the least hospitable laying ground of all examined plant species.

A note on Figure 25; the numbers used to create this bar graph consisted of the combined final egg sack cluster counts for all cages. *Oryza rufipogon* was omitted from this graph for the very reason that egg sack clusters for its 5 cages were not recorded over the same length of time. The 16 snail count cage for *Panicum repens* and the 8 snail count cage for *Eleocharis dulcis* also had premature ends when the cages were stolen between day 4 and day 6 of the experiment. The data for these two plant species were still used, however, in an effort to be able to extrapolate findings for the five plant species overall.

Figure 26 shows the preferred egg sack cluster laying areas for the overall experiment. As the pie chart shows, the presence of the eucalyptus poles on the interior of the netted cages had a large effect on the overall experiment. 50% of the time, *Pomacea canaliculata* laid egg sacks on these poles. Of the four plant species (*Oryza rufipogon* data was unusable), *Melaleuca cajuputi* was the most preferred species, providing habitat for 22% of all egg sacks laid. From greatest percentage to smallest percentage, the following plant species ranked in the following order: *Panicum repens*, *Eleocharis dulcis*, and *Eleocharis atropurpurea*. This directly correlates with the height of the plant species. Since all other measured variables of the cage habitats were fairly similar, it could be concluded that the height of a plant is the most important factor that enables *Pomacea canaliculata* to lay egg clusters.

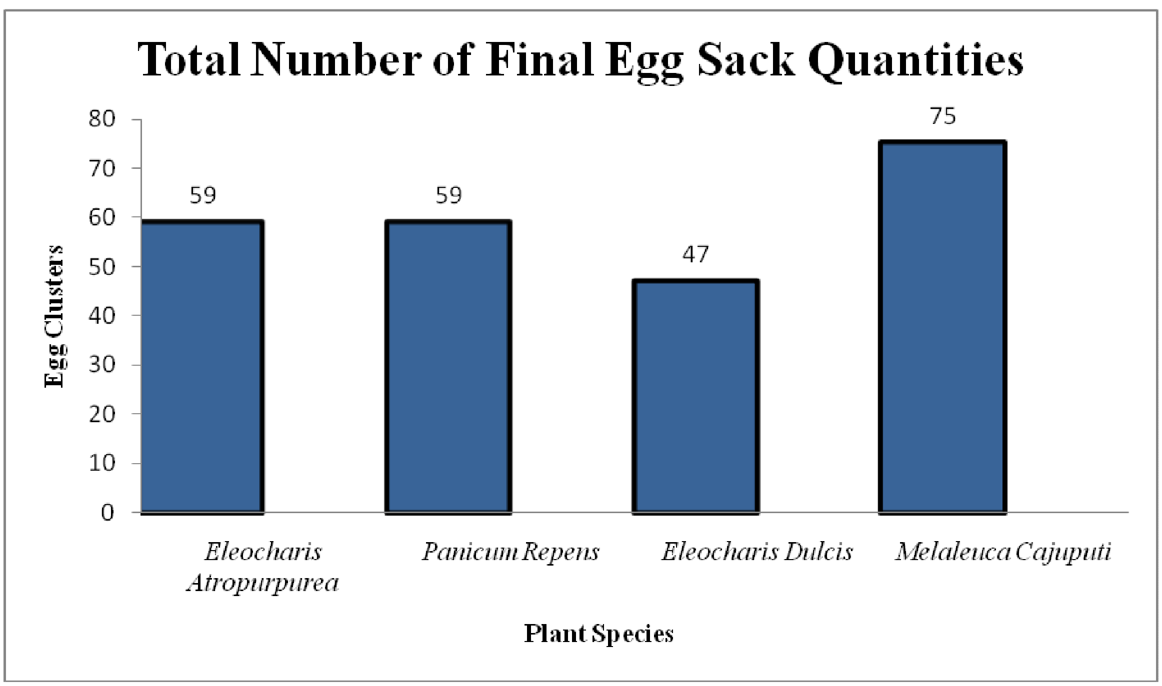


Figure 25. Final Egg Sack Quantities

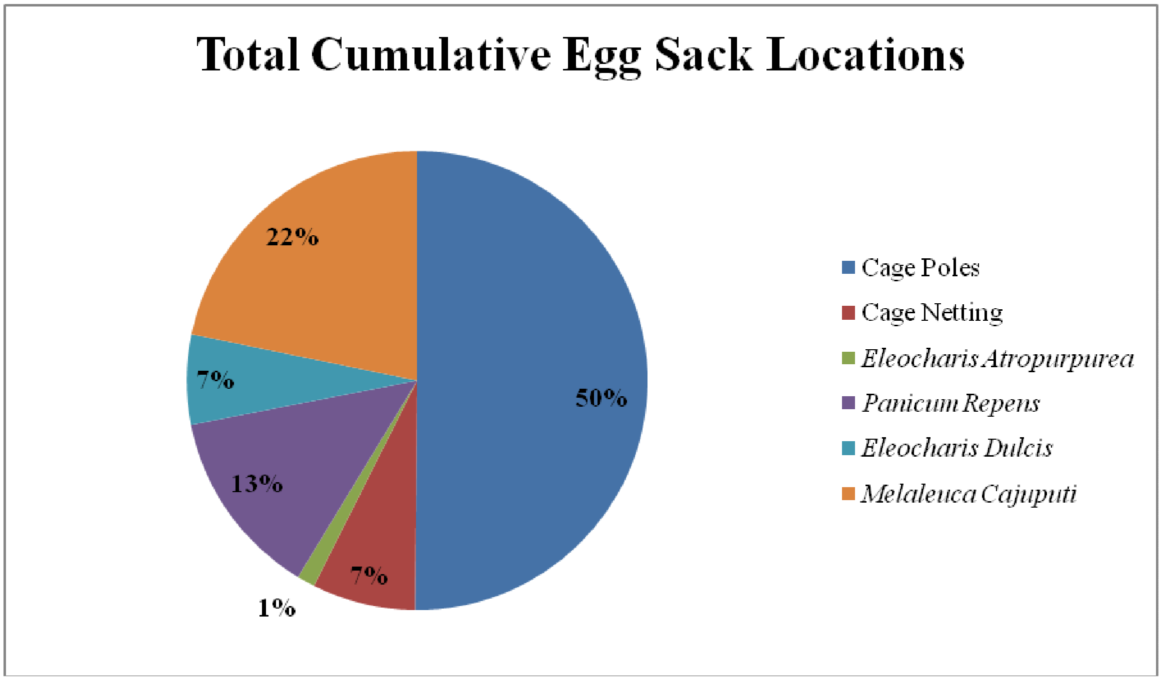


Figure 26. Total Cumulative Egg Sack Locations

4.2 Conclusion for Study Question 2

Just as important as knowing where *Pomacea canaliculata* can survive and thrive is knowing how *Pomacea canaliculata* can survive and thrive. To further examine this, data was collected at regular intervals within each cage to determine how different densities of *Pomacea canaliculata* were altering the existing chemical and ecological balances that existed within each plant area.

Data on nitrate, phosphate, and iron levels was collected using Hanna Instruments readers. Due to faulty and/or inapplicable machinery, the data for these three indicators cannot be used. Please refer to all appendix data entries to see the results of this data entry.

Data on pH, electric conductivity, and dissolved oxygen was successfully collected at all five plant examination areas. Each of these values followed a very specific pattern over the course of the experiment, regardless of snail density. The controls for each area showed similar levels of pH, electrical conductivity, and dissolved oxygen. Even among the different plant sites, several trends were noticeable, indicating a change of larger proportions that was applicable to the entire A1 area of Tram Chim National Park. For instance, all dissolved oxygen content levels for all control cages and all snail densities followed the trend depicted in Figure 27. From this data, it can be concluded that differing densities of *Pomacea canaliculata* have no significant impact on naturally occurring levels of pH, electric conductivity, and dissolved oxygen.

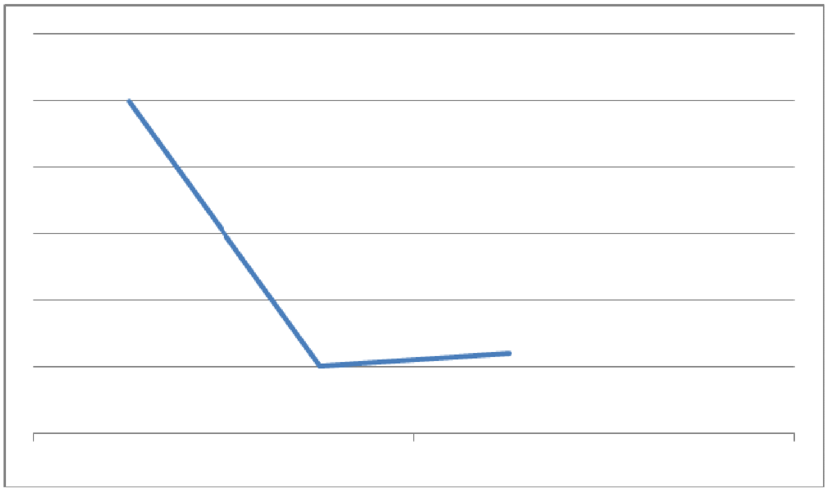


Figure 27. Dissolved Oxygen Overall Trend

4.3 Suggestions for the Future

4.3.1 *Pomacea Canaliculata* Selection

One aspect of this experiment that was totally ignored was the sex of the snails. In retrospect, the ability to properly replicate reproductive patterns of *Pomacea canaliculata* depends entirely on the sex of the snail. Easily distinguishable by the lip of the shell, equal numbers of both sexes should be placed within each cage for future experiments (Ghesquiere, 2001). Figure 28 shows the physical differences between the two sexes.

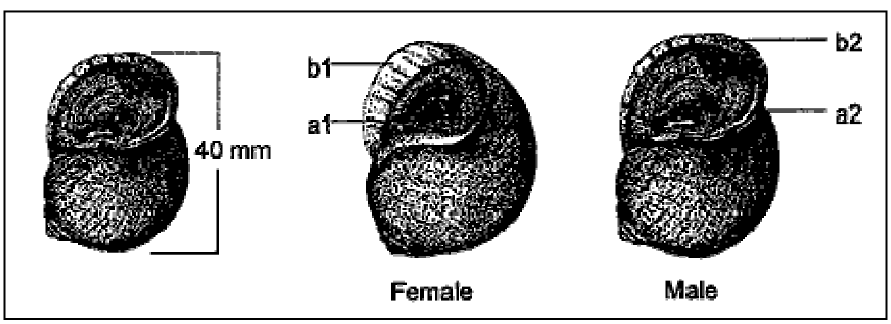


Figure 28. Physical Comparison of P. Canaliculata Sexes (Ghesquiere, 2001)

4.3.2 Cage Design

Although the cage design was an improvement from Ann Huston's SIT experiment in Fall 2008, there are still many ways in which the cage for this experiment can be improved. Due to all cages being stolen before the proposed end date of the experiment, it is not known whether the cages were successful in keeping *Pomacea canaliculata* within the cage area. However, the method employed wherein sharpened sticks were placed approximately every 10 cm to push the net edges deep into the mud seemed to provide a sealed environment.

The net should also be sealed on top, as it was in this experiment. Excess net should be cut away so as to stop knotted netting from dipping into the observation area or blocking sunlight. If possible, arrange for the net to be sewn at the Tram Chim town market so as to create a perfect seal with no extra net. As was intended in this experiment but not carried out, all efforts should be made to place cage support poles on the outside of the netting. In an effort to replicate the natural environment and have the cage remain as non-intrusive as possible, *Pomacea canaliculata* should not be able to reach the support poles. Figure 29 is a rough sketch of what an ideal cage might look like. As a final note, it might be worth erecting a sign in Vietnamese that explains the nature of the project and how it could benefit the local community. This seems to be the most neutral and potentially successful way to avoid having cage netting stolen again.

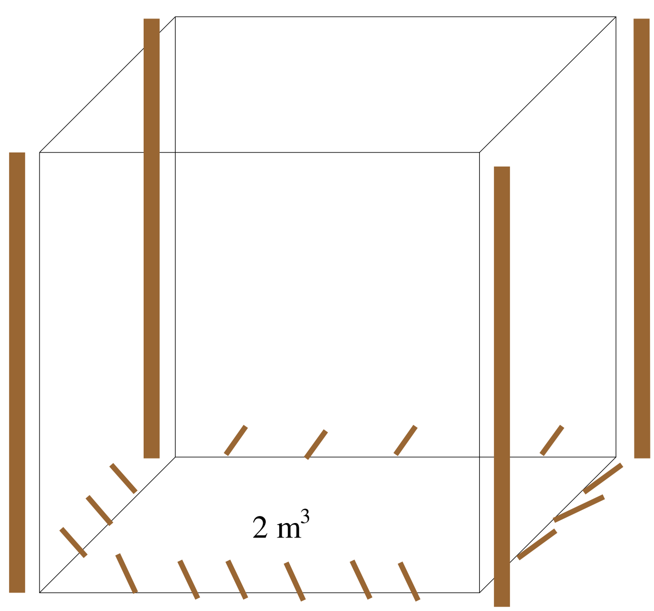


Figure 29. Snail Cage Design Example

4.3.3 Data Collection

In order to properly monitor nitrate, phosphate, and iron levels within the experimentation area, proper equipment will need to be used. Perhaps the existing Hanna Instruments can be manipulated somehow to show proper readings, but in their current state they are unusable.

A more methodic strategy needs to be employed to be able to measure vegetation damage done by *Pomacea canaliculata*. In Ann Huston's experiment, she measured damage as an overall percentage, defined by yellowing plants and cut stems. She may have been successful in her observations, although in this past experiment, "yellowing plants and cut stems" were either not observed or not deemed applicable to *Pomacea canaliculata* damage. It is possible that Ms. Huston's smaller cage size of 1 meter by 1 meter allowed vegetation damage to be more evident, although there is no way of knowing this.

Photographic comparisons of vegetation within each cage could be a solution to this problem. In this way, vegetation change over time could be examined more directly. An experiment might also be carried out for the sole purpose of determining how *Pomacea canaliculata* independently damages each of the five plant species. With this information, the staff of Tram Chim National Park would be able to more accurately determine if vegetation damage throughout the park was caused by *Pomacea canaliculata*.

4.3.4 Uncontrolled Variables

One of the most difficult aspects of this experiment was deciding where to draw the line between this project being a controlled laboratory experiment and a field site observation. Most certainly, it is important to keep all *Pomacea canaliculata* contained within their respective cages, but there are other factors that one has to consider as well. One of the most important aspects of *Pomacea canaliculata*'s ability to live depends on the water depth of its habitat. Therefore, all effort should be made to have all cages placed within similar water depths.

Another uncontrolled variable that most certainly affects the ability of this experiment to be successful is the time of year. In the wet season, *Pomacea canaliculata* are significantly more active, allowing experiments to be carried out with greater intensity and scale. During the dry season, many *Pomacea canaliculata* will naturally bury themselves in the mud to wait for rains to come (Ghesquiere, 2001). Although the transition from dry to wet season was occurring during this experiment, it's possible that the time of year effected the normal processes of *Pomacea canaliculata*.

4.4 Final Thoughts

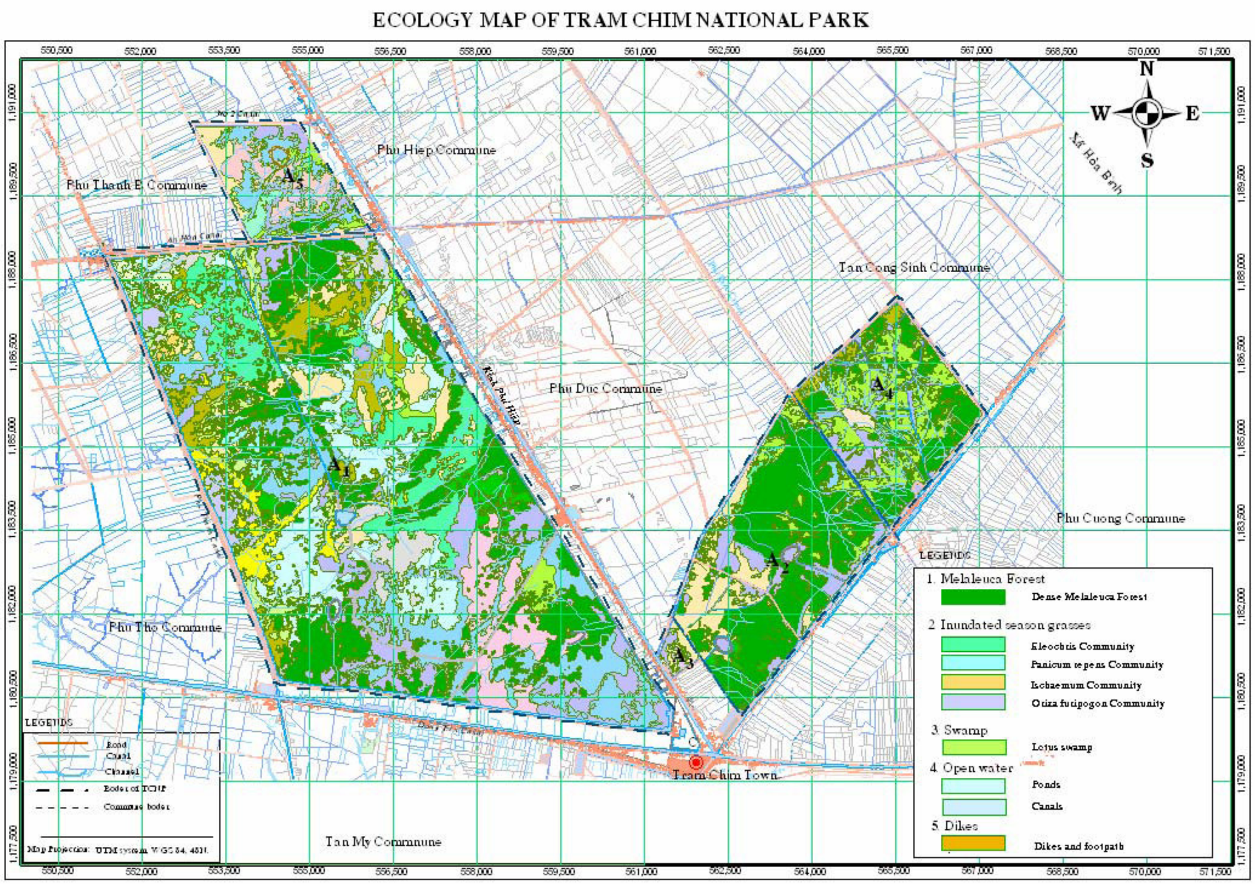
This experiment attempted to answer many questions, and was successful on many counts. However, more important than the resolved answers are the more defined and direct questions that this project has laid out for future research. Much of the experiment can be replicated without significant change, but the methodology and data collection process for the experiment will have changed dramatically from its original layout in this research project.

Pomacea canaliculata is a serious threat to Tram Chim National Park. Its presence within the park is growing and, with forced flooding of certain zones of the park, it has the ability to quickly mushroom into a disastrous pest invasion. The staff is aware of the dangers of *Pomacea canaliculata*, but limited labor and resources make any significant research impossible. Without knowing the answer to some of the most basic questions, Tram Chim National Park cannot take action.

The main conclusion that this experiment made was to determine the ability for *Pomacea canaliculata* to reproduce within different populations of local vegetation. This project also provided sufficient data on the preferences of egg sack locations for *Pomacea canaliculata*. However, many questions remained unanswered: to what extent does *Pomacea canaliculata* damage local vegetation, how quickly can it spread, where does it exist most densely within the park, how important is egg sack location in relation to habitat location. All these questions and more are tasks for future researchers. The process is arduous and tasking, but each step towards a basic overall knowledge of *Pomacea canaliculata*'s existence within the park brings the Tram Chim National Park closer to creating a protective environment for all aspects of the local ecosystem.

5. APPENDIX

A. Ecology Map of Tram Chim National Park (Quoi, 1998)



B.1 *Eleocharis atropurpurea* - Control

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	10:49		34	232	15.4	18.33				720	0	0	0	0
2	8:05	6.41	30.1	235						720	0	0	0	0
4	8:45	5.2	29.6	228	38.8	15	3.5	2.75	0.53		0	0	0	0
6	10:49	6.59	34	256	6.63	10	0	0.59	1.72		0	0	0	0
8	8:04	6.57	28.2	254	5.7	10	0.4	2.69	2.46		0	0	0	0
12	STOLEN													
14														

B.2 *Eleocharis atropurpurea* – 8 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	10:49		36	192.5	21.3	16				200	0	0	0	0
2	8:05	6.3	28.7	200			0.6	0.54	"LO"		4	1	0	5
4	8:45	5.6	30	211	59.7	11	1.5	2.38	1.62		8	1	0	9
6	10:49	6.6	30.3	223	8.2	12.5	0	2.69	"LO"		1	2	0	3
8	8:04	6.46	28.4	225	6.8	10	0	1.12	1.92		1	1	0	2
12	STOLEN													
14														

B.3 *Eleocharis atropurpurea* – 16 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	10:49		33	210	4.6	13				1600	0	0	0	0
2	8:05	6.59	28.7	223			10.6	0.61	"LO"	1600	4	1	0	5
4	8:45	6.2	28	206	62.2	11.5	0	2.75	2.05		7	1	0	8
6	10:49	7.2	32	216	5.7	10	0	1.41	"LO"		9	1	0	10
8	8:04	6.59	28.7	216	6.5	11.5	0	1.15	3.22		11	0	0	11
12	STOLEN													
14														

B.4 *Eleocharis atropurpurea* – 24 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	10:49		32	239	0.7	14.63				1200	0	0	0	0
2	8:05	6.12	29.4	227			0	0.47	"LO"	1200	17	0	2	19
4	8:45	6.5	29.5	233	35.9	13.5	0	2.75	2.49		29	2	1	32
6	10:49	6.4	31	232	6.9	11	0	1.38	2.08		33	4	1	38
8	8:04	6.13	28.4	228	6.5	11.5	0	2.72	1.78		37	5	4	46
12	STOLEN													
14														

C.1 *Panicum repens* - Control

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	11:20		33	185.7	4.2	8.63				240	0	0	0	0
2	9:26	6.67	32.7	200			0	0.51	"LO"	240	0	0	0	0
4	9:30	5.1	31.8	223	51.7	9.5	1.1	2.75	"LO"		0	0	0	0
6	9:50	6.89	34.0	226	5.8	10	"LO"	0	2.75		0	0	0	0
8	8:30	6.72	28.7	254	7.2	11.5	0	1.99	3.53		0	0	0	0
12	STOLEN													
14														

C.2 *Panicum repens* – 8 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	11:20		34.0	234	3.3	14				240	0	0	0	0
2	9:26	6.66	31.3	223			0	0.41	"LO"	240	0	1	3	4
4	9:30	4.6	30.2	219	20.1	10.5	0.7	2.75	"LO"		0	1	4	5
6	9:50	6.76	32	218	5.6	11	0	2.75	2.74		1	2	7	10
8	8:30	6.76	28	228	7.5	13	3.4	0.31	2.89		0	3	5	8
12	STOLEN													
14														

C.3 *Panicum repens* – 16 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	11:20		37	195.5	1.2	10				320	0	0	0	0
2	9:26	6.83	29.4	258			0	0.93	"LO"	320	3	0	3	6
4	9:30	4.8	32	253		9	0	1.41	"LO"		0	0	5	5
6	STOLEN													
8														
12														
14														

C.4 *Panicum repens* – 24 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	11:20		34	211	6.1	14.3				320	0	0	0	0
2	9:26	6.81	30.8	241			0	2.75	"LO"	320	4	1	9	14
4	9:30	5.4	33	266		9	"LO"	0.43	"LO"		11	4	11	26
6	9:50	6.82	33.4	279	5.6	9.5	0	0.97	0		21	3	18	42
8	8:30	6.83	29	295	7.8	14.5	0.6	2.34	"LO"		22	5	19	46
12	STOLEN													
14														

D.1 *Eleocharis dulcis* – control

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	12:00		35	190.5	6.1	20				1000	0	0	0	0
2	10:19	6.4	28.2	212			2.1	0.2	"LO"	1000	0	0	0	0
4	10:20	4.7	33	192.7	8.3	16	0.4	2.75	"LO"		0	0	0	0
6	9:00	6.17	29.8	189	16.4	15.5	0	1.04	"LO"		0	0	0	0
8	9:01	6.9	29	238	6.8	16	0	1.67	2.88		0	0	0	0
12	STOLEN													
14														

D.2 *Eleocharis dulcis* – 8 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	12:00		32	230	3.3	24				800	0	0	0	0
2	10:19	6.61	30.2	225			3.9	0.1	"LO"	800	1	0	2	3
4	10:20						0	2.75	"LO"					
6	STOLEN													
8														
12														
14														

D.3 *Eleocharis dulcis* – 16 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	12:00		33	202	3.3	22				1200	0	0	0	0
2	10:19	6.81	28.6	243			3.5	2.73	"LO"	1200	5	0	5	10
4	10:20	4.7	31	205	4.8	13.5	0	1.83	"LO"		7	2	6	15
6	9:00	6.7	30	240	10.9	10	"LO"	"LO"	"LO"		9	0	8	17
8	9:01	6.8	30	229	7.8	13	"LO"	1.47	"LO"		10	0	7	17
12	STOLEN													
14														

D.4 *Eleocharis dulcis* – 24 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	12:00		36	180	5.1	17				1000	0	0	0	0
2	10:19	6.51	30.7	178.4			0	1.69	"LO"	1000	1	0	2	3
4	10:20	4.7	33	207	12.5	11.5	0	1.77	"LO"		4	0	1	5
6	9:00	6.74	31	173	20.8		0	0.68	1.9		7	0	5	12
8	9:01	6.7	29	181	5.9	13.5	0.9	2.43	3.75		16	0	4	20
12	STOLEN													
14														

E.1 *Melaleuca cajuputi* - Control

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	12:45		38	112.4	3.7	12				2	0	0	0	0
2	11:05	7.08	36.1	216			0.4	0.66	"LO"	2	0	0	0	0
4	11:00	4.1	34.6	266	8.1	7	0	2.31	3.18	2	0	0	0	0
6	11:20	6.7	33.6	247	5.7	9	"LO"	2.68	"LO"	2	0	0	0	0
8	9:45	6.78	30.8	309	7.3	9	0.3	1.52	2.4	2	0	0	0	0
12	STOLEN													
14														

E.2 *Melaleuca cajuputi* – 8 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	12:45		38.6	231	13.3	12				5	0	0	0	0
2	11:05	6.39	30.6	232			2.5	0.85	"LO"	5	1	1	4	6
4	11:00	4.1	37	239	7.5	7	"LO"	0.65	3.28	5	3	0	3	6
6	11:20	6.8	34.6	258	5	7	0	1.06	"LO"	5	1	0	8	9
8	9:45	6.52	30.7	367	5.2	7.5	0	2.66	"LO"	5	4	0	6	10
12	STOLEN													
14														

E.3 *Melaleuca cajuputi* – 16 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (μs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	12:45		38	197	12.1	14.5				7	0	0	0	0
2	11:05	6.46	29.1	186.2			0	2.75	"LO"	7	2	0	2	4
4	11:00	4.7	31.6	220	12.3	9	"LO"	2.75	"LO"	7	0	1	4	5
6	11:20	6.1	33.7	245	5	8	0	0.79	2.24	7	1	0	8	9
8	9:45	6.71	31.3	263	5.9	9.5	0.4	2.45	4.33	7	9	0	10	19
12	STOLEN													
14														

E.4 *Melaleuca cajuputi* – 24 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (μs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	12:45		34	192	6.1	11				8	0	0	0	0
2	11:05	6.61	31.7	234			0	0.53	"LO"	8	0	1	16	17
4	11:00	5.2	34	243	6.3	9	0	1.94	3.48	8	0	0	30	30
6	11:20	6.8	32.4	243	6.6	9	"LO"	1.19	"LO"	8	13	2	16	31
8	9:45	6.6	30	251	5.8	11	0	0.48	3.63	8	15	0	31	46
12	STOLEN													
14														

F.1 *Oryza rufipogon* -
control

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	9:00		33	195.6	4.9					500	0	0	0	0
2	12:26	6.47	38.1	281			"LO"	"LO"			0	0	0	0
Water Buffalo - NEW TRIAL														
0	12:10	4.9	34	304	8.7	19.5	0	2.61	"LO"		0	0	0	0
2	12:11	6.7	35.6	233	5.9	24	0	1.77	"LO"		0	0	0	0
4	11:00	6.64	31.5	294	14.2		0	2.16	"LO"		0	0	0	0
8	8:25	6.69	29.5	236	7.1	17.5	0	2.75	"LO"		0	0	0	

F.2 *Oryza rufipogon* – 8 snail
count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	9:00		32.3	212	5.7	31.3				225	0	0	0	0
Water Buffalo - Continuation of Experiment														
2	12:26	6.46	35.8	285			"LO"	"LO"			0	0	6	6
4	12:10	4.4	34	345	4.3	17.5	0	0.99	"LO"		4	0	0	4
6	12:11	6.6	36	231	4.8	19	0	1.79	"LO"		5	0	5	10
8	11:00	6.55	33	244	17		0	0.71	"LO"		6	0	4	10
12	8:25	6.77	29.8	218	7.7	17	0	0	"LO"		6	0	4	10

F.3 *Oryza rufipogon* – 16 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	9:00		32	223	2.7	14				255	0	0	0	0
2	12:26	6.24	37.4	267			3.4	0.05			0	0	4	4
Water Buffalo - NEW TRIAL														
0	12:10	5.3	35	251	3.8	22.5	0.3	2.79	2.89	270	0	0	0	0
2	12:11	6.6	34.5	214	7.6	17.5	0	2.75	"LO"		0	0	0	0
4	11:00	6.68	32	223	14.1		"LO"	0.74	"LO"		0	0	1	1
8	8:25	6.53	29.8	258	8.5	19.5	"LO"	"LO"	"LO"		0	0	0	0

F.4 *Oryza rufipogon* – 24 snail count

Day	Time	pH	T (°C)	Electrical Conductivity (µs/cm)	Dissolved Oxygen (%)	Water Depth (cm)	Nitrate (ppm)	Phosphate (ppm)	Iron (ppm)	Stem Count	Stick Egg Sack Count	Net Egg Sack Count	Plant Egg Sack Count	Total Egg Sack Count
0	9:00		32	173	70.8	19.6				325	0	0	0	0
2	12:26	6.79	38.4	185.6			0.9	0.5			0	0	4	4
4	**Water Buffalo - ABANDONED**													
6														
8														
12														
14														

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